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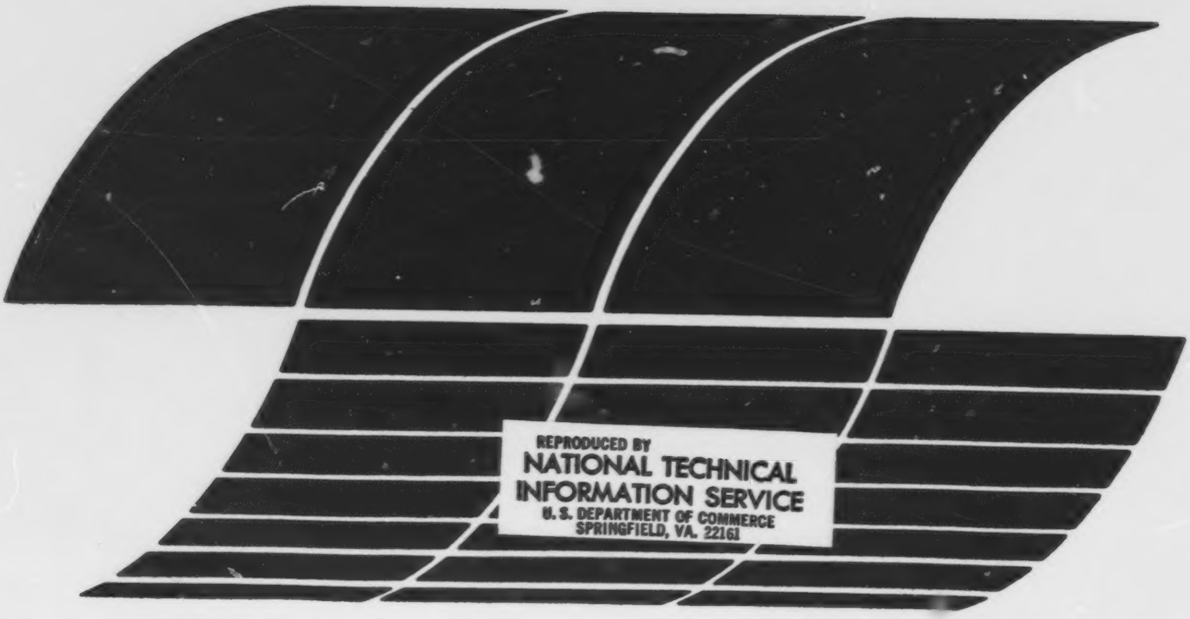

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The report is an integrated evaluation of air emissions, water effluents, solid wastes, toxic substances, control/disposal alternatives, environmental regulatory requirements, and environmental effects associated with solvent refined coal (SRC) systems. It considers the SRC-I (solid product) and SRC-II (liquid product) variations of solvent refining in terms of a hypothetical facility to produce 7950 cu m/day liquefied coal products. Discussions emphasize SRC-II production, identifying differences applicable to SRC-I production. An overview of the SRC system processes is followed by characterizations of applicable input materials, process streams, waste streams, products, and byproducts. Control and disposal options are surveyed to determine their applicability to subject discharges. Potentially applicable regulatory requirements are reviewed and compared to estimated after-treatment discharge levels. Source Analysis Model (SAM) analyses indicate that solid wastes produced by SRC systems are the greatest source of current environmental concern. The major environmental difference between SRC-I and SRC-II systems is the potential for particulate emissions of SRC-I solid product dust. Additional information needs for future environmental assessment are discussed. Supplemental information pertinent to the discussions is included in appendices.

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Liquefaction	Solvent Refined Coal	07D
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by

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ABSTRACT

This Environmental Assessment Report is an integrated evaluation of air emissions, water effluents, solid wastes, toxic substances, control/disposal alternatives, environmental regulatory requirements and environmental effects associated with Solvent Refined Coal (SRC) systems.

Both the SRC-I (solid product) and SRC-II (liquid product) variations of solvent refining are considered in terms of a hypothetical facility to produce 7,950 cubic meters per day liquified coal products. To prevent unnecessary redundancy, discussions emphasize SRC-II production, identifying any differences applicable to SRC-I production as required. Following an overview of the processes comprising SRC systems, characterizations of applicable input materials, process streams, waste streams, products and by-products are made. Based on available stream characterization data, available control and disposal options are surveyed to determine their applicability to the subject discharges. A review of potentially applicable regulatory requirements is made and compared to estimated after treatment discharge levels.

In addition the environmental effects attributable to treated discharges are evaluated using the Multimedia Environmental Goals (MEGs), and Source Analysis Models (SAMs) methodologies. Based on SAM analysis of the existing data, solid wastes produced by SRC systems are considered the greatest source of current environmental concern. In terms of environmental assessment, the major difference between SRC-I and SRC-II systems is the potential for particulate emissions in the form of SRC-I solid product dust.

A discussion of additional information needs for future environmental assessment work is presented. Supplemental information pertinent to the discussions presented in the body of the report is included in the Appendices.

TABLE OF CONTENTS

Page

Abstract ii

List of Figures xi

List of Tables xviii

List of Abbreviations xxx

Nomenclature xxxii

Acknowledgements xxxiii

1.0 SUMMARY 1

- 1.1 Overview of Solvent Refined Coal Systems 2
  - 1.1.1 SRC-II Liquefaction 3
  - 1.1.2 SRC-I Liquefaction 7
  - 1.1.3 Auxiliary Processes in SRC Systems . . 7
- 1.2 Waste Streams and Pollutants of Major Concern 12
  - 1.2.1 Waste Streams to Air 12
  - 1.2.2 Waste Streams to Water 17
  - 1.2.3 Solid Wastes 20
  - 1.2.4 Toxic Substances 23
- 1.3 Status of Environmental Protection Alternatives 25
  - 1.3.1 Air Emissions Controls 25
  - 1.3.2 Water Effluents Control. 28
  - 1.3.4 Control of Solid Wastes 30
- 1.4 Data Needs and Recommendations 30

2.0 PROCESS DESCRIPTION OF SOLVENT REFINED COAL SYSTEMS 38

- 2.1 Technical Overview of Solvent Refined Coal Systems 38

TABLE OF CONTENTS (continued)

Page

2.1.1 Status of Development 38
2.1.2 Industrial Applicability of SRC Systems 43
2.1.3 Input Materials, Products and By-Products 44
2.1.4 Energy Efficiencies 46
2.1.5 Capital and Operating Costs 47
2.1.6 Commercial Prospects 50

2.2 Description of Processes 51

2.2.1 Generalized System Flow Diagrams . . . 51
2.2.2 Coal Pretreatment. 55
2.2.3 Liquefaction 65
2.2.4 Separation 69
2.2.5 Purification and Upgrading 77
2.2.6 Auxiliary Processes. 85

2.3 Process Areas of Current Environmental Concern . 133

2.3.1 Coal Pretreatment 133
2.3.2 Coal Liquefaction 134
2.3.3 Separation 134
2.3.4 Purification and Upgrading 135
2.3.5 Auxiliary Processes. 136

3.0 CHARACTERIZATION OF INPUT MATERIALS, PRODUCTS, AND WASTE STREAMS 138

3.1 Summary of Sampling and Analytical Activities. . 138

3.1.1 IERL/RTP Environmental Assessment Activities 138
3.1.2 Non-IERL/RTP Evaluations of the SRC Systems 151

3.2 Input Materials 163

3.2.1 Regional Characterization of U.S. Coals 163
3.2.2 Regional Characterization of U.S. Surface and Groundwaters 174

CONTENTS (Continued)

Page

3.3 Process Streams 184

3.3.1 Coal Pretreatment. 184
3.3.2 Coal Liquefaction 189
3.3.3 Separation 189
3.3.4 Purification and Upgrading 191
3.3.5 Auxiliary Processes. 192

3.4 Toxic Substances in Products and By-Products . . 194

3.4.1 Inorganic Analysis 198
3.4.2 Organic Analysis 205

3.5 Waste Streams to Air 209

3.5.1 Coal Pretreatment. 211
3.5.2 Coal Liquefaction 215
3.5.3 Separation 215
3.5.4 Purification and Upgrading 216
3.5.5 Auxiliary Processes. 216

3.6 Waste Streams to Water 233

3.6.1 Coal Pretreatment. 234
3.6.2 Coal Liquefaction 234
3.6.3 Separation 236
3.6.4 Purification and Upgrading 236
3.6.5 Auxiliary Facilities 237

3.7 Solid Wastes to Final Disposal 252

3.7.1 Coal Pretreatment. 252
3.7.2 Coal Liquefaction, Gas Separation and Hydrotreating 252
3.7.3 Fractionation 253
3.7.4 Solids/Liquids Separation Process. . . 253
3.7.5 Auxiliary Processes 257
3.7.6 Process Sludges 257
3.7.7 Steam Generation 262
3.7.8 Hydrogen Generation 265

CONTENTS (continued)

Page

4.0 PERFORMANCE AND COST OF CONTROL ALTERNATIVES 267

4.1 Procedures for Evaluating Control Alternatives . 267
4.2 Air Emission Control Alternatives 268

4.2.1 Coal Pretreatment 270
4.2.2 Coal Liquefaction Operation 271
4.2.3 Separation 272
4.2.4 Purification and Upgrading 273
4.2.5 Auxiliary Processes. 273

4.3 Water Effluent Control Alternatives 279

4.3.1 Coal Pretreatment Operation. 279
4.3.2 Coal Liquefaction Operation 281
4.3.3 Separation 281
4.3.4 Purification and Upgrading 281
4.3.5 Auxiliary Processes. 282

4.4 Solid Waste Control Alternatives 286

4.4.1 Coal Pretreatment. 286
4.4.2 Coal Liquefaction. 286
4.4.3 Separation 286
4.4.4 Purification and Upgrading 288
4.4.5 Auxiliary Processes. 288

4.5 Toxic Substances Control Alternatives 289
4.6 Summary of Most Effective Control Alternatives . 290

4.6.1 Emissions Control 291
4.6.2 Effluents Control 291
4.6.3 Solid Wastes Control 297
4.6.4 Toxic Substances Control 297

4.7 Multimedia Control Alternatives 297
4.8 Regional Considerations Affecting Selection of Alternatives 301
4.9 Summary of Cost and Energy Considerations . . . 307

4.9.1 Air Emissions Control Alternatives . . 307
4.9.2 Water Effluents Control Alternatives . 315
4.9.3 Solid Wastes Control Alternatives. . . 316

CONTENTS (continued)

Page

5.0 ANALYSIS OF REGULATORY REQUIREMENTS AND ENVIRONMENTAL IMPACTS 319

5.1 Environmental Impact Methodologies 319

5.1.1 Multimedia Environmental Goals 319
5.1.2 Source Analysis Models 340
5.1.3 Bioassay Interpretations 358
5.1.4 Joint Site Selection and Impact Assessment Methods 375

5.2 Impacts on Air 379

5.2.1 Summary of Air Standards and Guidelines 379
5.2.2 Comparisons of Waste Streams With Emission Standards 400
5.2.3 Impacts on Ambient Air Quality 409
5.2.4 Potential Ecological and Health Effects of Unregulated Air Pollutants. 412

5.3 Impacts on Water 414

5.3.1 Summary of Water Standards 414
5.3.2 Comparisons of Waste Streams with Effluent Standards 441
5.3.3 Impact on Ambient Water Quality . . . 442
5.3.4 Evaluation of Unregulated Pollutants and Bioassay Results 450

5.4 Impacts of Land Disposal 450

5.4.1 Summary of Final Land Disposal Standards. 450
5.4.2 Comparison of Waste Streams with Disposal Standards 466
5.4.3 Evaluation of Unregulated Pollutants and Bioassay Results 468

CONTENTS (continued)

Page

5.5 Product Impacts. 485

- 5.5.1 Summary of Toxic Substances Standards. 485
- 5.5.2 Comparison of Product Characterization Data with Toxic Substances Standards 487
- 5.5.3 Environmental Impacts. 487
- 5.5.4 Evaluation of Unregulated Toxic Substances and Bioassay Results. . 502

5.6 Radiation and Noise Impacts. 518

- 5.6.1 Radioactivity. 519
- 5.6.2 Noise. 519
- 5.6.3 Thermal Factors. 521
- 5.6.4 Potential Ecological and Health Effects of Radiation, Noise, and Thermal Emissions. 522

5.7 Summary of Major Environmental Impacts . . . 527

- 5.7.1 Air Impacts. 536
- 5.7.2 Water Impacts. 538
- 5.7.3 Impacts of Solid Wastes. 538
- 5.7.4 Product Impacts. 538
- 5.7.5 Other Impacts. 547

5.8 Siting Considerations. 551

- 5.8.1 Major Stages and Steps of the SRC Siting Methodology 554
- 5.8.2 Basic Siting Considerations. . . . 559
- 5.8.3 Basic Exclusions 560
- 5.8.4 Suggested EPA Regions for Siting Synfuels Plants. 561

6.0 SUMMARY OF NEEDS FOR ADDITIONAL DATA. 562

6.1 Categories of Data Needs 562

- 6.1.1 Data Needs to Support Standards Development and Enforcement. . . . 562
- 6.1.2 Data Needs to Support Effects and Control Technology Research and Development. 569

CONTENTS (continued)

Page

6.2 Data Acquisition by Ongoing Environmental Assessment Activities. 573

6.2.1 Ongoing IERL-RTP Environmental Assessment Activities. 573
6.2.2 Other Ongoing Environmental Assessment Activities. 573

REFERENCES 578

APPENDICES. 594

A. Glossary 595
B. Metric Conversion Factors. 603
C. Quality of Rivers of the United States . . . 606
D. Pollution Control Alternatives 632

D-1 Air Emission Control Alternatives . . . 632
D-2 Water Effluent Control Alternatives . . 663
D-3 Solids Treatment Alternatives 693
D-4 Final Disposal Alternatives for Solid Wastes. 712

E. Baseline Factors for SRC-II Development. . . 747

E-1 Planning and Design Factors 747
E-2 Government Rulemaking Factors - Environmental Requirements. 748
E-3 Source Factors and Their Interactions . 751
E-4 Dissipative Forces. 753
E-5 Development and End Impacts 755

E-6 Standards Applicable to SRC Development 758
E-7 Siting Considerations 778

FIGURES

Number		Page
1	SRC-II system	6
2	SRC-I system	8
3	Auxiliary processes in SRC systems	10
4	Air emissions from SRC systems	13
5	Sources of water effluents in SRC systems	18
6	Sources of solid wastes in SRC systems	22
7	Controls for air emissions from SRC systems	26
8	Control of water effluents in SRC systems	29
9	Control of solid wastes in SRC systems	31
10	Fort Lewis SRC pilot plant	32
11	Current schedule for SRC research and development	42
12	Overall material balance for SRC-II systems with product capacity of 7,950 m^3/day (8,699 mg/day)	45
13	Generalized flow diagram of SRC-II system	53
14	Generalized flow diagram of SRC-I system	56
15	Process modules of coal receiving, storage, and pretreatment facilities	57
16	Block flow diagram of coal pretreatment operation (SRC-II mode)	60
17	Process module diagram of the coal liquefaction operation	66
18	Block flow diagram of liquefaction operation (SRC-II mode)	68
19	Process modules of gas separation process (SRC-II mode)	70

FIGURES (continued)

Number Page

20 Block flow diagram of gas separation process (SRC-II mode) 73

21 Process flow schematic: solids/liquids separation process (SRC-II mode) 75

22 Two solidification alternatives 76

23 Block flow diagram of solids/liquids separation process (SRC-II mode) 78

24 Process flow schematic: fractionation process (SRC-II mode) 80

25 Block flow diagram of fractionation process . 81

26 Process flow schematic: hydrotreating process (SRC-II mode) 83

27 Block flow diagram of hydrotreating process (SRC-II mode) 86

28 Block flow diagram of coal receiving and storage (SRC-II mode) 88

29 A typical raw water treatment process 90

30 Block flow diagram of water supply 93

31 Typical water cooling process 94

32 Block flow diagram of water cooling process . 96

33 Steam generation facilities 99

34 Block flow diagram of steam generation 100

35 Hydrogen generation auxiliary process 102

36 Block flow diagram of hydrogen generation process 105

37 Typical oxygen generation process 107

38 Block flow diagram of oxygen generation process 109

FIGURES (continued)

Number		Page
39	Schematic of MEA acid gas removal process . . .	111
40	Block flow diagram of acid gas removal	114
41	Schematic of Stretford sulfur recovery with high temperature hydrolysis	116
42	Block flow diagram of sulfur recovery	119
43	Process flow schematic: hydrocarbon/hydrogen recovery	121
44	Block flow diagram of hydrocarbon/hydrogen recovery process	123
45	Process flow schematic of ammonia recovery . . .	125
46	Block flow diagram of ammonia recovery process .	127
47	Typical solvent extraction phenol recovery process	128
48	Block flow diagram of phenol recovery process. .	130
49	Block flow diagram of product/by-product storage facilities (SRC-II mode)	132
50	Interrelationships among general areas involved in preparing an environmental test plan	139
51	Air emissions discharged from SRC systems . . .	269
52	Sources of wastewater effluent discharges in SRC systems	280
53	Sources of solid wastes in SRC systems	287
54	Two wastewater treatment alternatives applicable to SRC systems	298
55	Zero discharge water management system for SRC-II	302
56	Background information sample summary for benzo(a)pyrene	322

FIGURES (continued)

Number		Page
57	Sample MEG chart	324
58	Sample SAM/IA worksheet for Level 1	350
59	Sample SAM/IA worksheet for Level 2	352
60	Sample SAM/IA worksheet for notes and assumptions	355
61	Sample SAM/IA summary sheet, Side 1	356
62	Example of a hierarchical system for evaluating the impacts of construction and operation of synfuel plants	377
63	Potential emissions from SRC-II basic unit operations and auxiliary process	401
64	Potential solid wastes from basic unit operation	467
65	Level 2 analysis for SRC mineral residue	475
66	Level 2 analysis for gasifier slag	482
67	Coal liquefaction environmental health and safety impact and hazard control requirements	494
68	Diagrammatic representation of a conceptualized SRC facility showing appropriate stream numbers	528
69	SAM/IA summary using average U.S. coal	529
70	SAM/IA summary using maximum U.S. coal	532
71	Power plant siting methodology	555
72	Overall flow schematic for the SRC-II pilot plant	567
73	Overall flow schematic of the SRC pilot plant wastewater system	568

FIGURES (continued)

		Page
74	Principal areas of water pollution.	607
75	Acid mine drainage.	608
76	Evaporation from open-water surfaces. . . .	609
77	Temperature of surface water - July and August.	610
78	Surface-water runoff (average annual) . . .	611
79	Flow of large rivers.	612
80	Dissolved solids content of surface water .	613
81	Saline surface-water.	614
82	Hardness of surface water	615
83	Concentration of sediment in streams. . . .	616
84	Natural fluoride in water supplies.	617
85	Thermal pollution.	618
86	Mean hardness as calcium carbonate at NASQAN stations during 1975 water year . .	619
87	Mean concentration of dissolved chloride at NASQAN stations during 1975 water year .	620
88	Mean concentration of dissolved solids measured as residue on evaporation (ROE) at 180°C at NASQAN stations during 1975 water year.	621
89	Mean concentration of dissolved zinc at NASQAN stations during 1975 water year. . .	622
90	Mean concentration of dissolved sulfate at NASQAN stations during 1975 water year. . .	623
91	Mean concentration of suspended sediment at NASQAN stations during 1975 water year. . .	624

FIGURES (continued)

Number		Page
92	Mean concentration of dissolved fluoride at NASQAN stations during 1975 water year .	625
93	Mean concentrations of total phosphorus as P at NASQAN stations during 1975 water year.	626
94	Mean alkalinity as calcium carbonate. . . .	627
95	Mean numbers of phytoplankton	628
96	Mean concentration of ammonia plus organic nitrogen as N	629
97	Mean concentration of total nitrite plus nitrite as N	630
98	Mean concentration of dissolved arsenic . .	631
99	Settling chamber configurations.	634
100	Conventional cyclone separator.	636
101	Beavon tailgas cleanup process.	661
102	SCOT process	662
103	Recommended values of F for various values of V_h/V_t	674
104	Three flow schemes employed in the dissolved air flotation process.	677
105	Moving belt concentrator yield vs. cake solids	704
106	Stream to air ratio at saturation in the reactor vapor space for various operation temperatures and pressures.	707
107	Reduction in COD resulting from sludge being exposed to excess air for one hour at various temperatures	708
108	High operation temperatures result in high COD reduction and low reaction time	708

FIGURES (continued)

Number		Page
109	Tank bottom drainage systems	720
110	Tank bottom replacement	722
111	Internal heating coil monitoring system	722
112	Tank filling control system	725
113	Navy boom	735
114	Kain boom	735
115	Boom/skimmer configuration for oil spill cleanup	736
116	Circulation pattern upstream of an air barrier in a current	736
117	Classes of skimmers	740
118	Diagram showing percolation of contaminants from a disposal pit to a water-table aquifer	785
119	Diagram showing how contaminated water can be induced to flow from a surface stream to a well	787
120	Plan view of a water-table aquifer showing the hypothetical areal extent to which specific contaminants of mixed wastes at a disposal site disperse and move	789

TABLES

Page

1 Key Events in the Development of Solvent Refined Coal Systems Including Projected Plans. 4

2 Air Emissions of Concern Associated With SRC Systems Based on SAM/IA Analysis 16

3 Water Effluents of Concern Associated With SRC Systems Based on SAM/IA Analysis. . 21

4 Solid Wastes of Concern Associated With SRC Systems Based on SAM/IA Analysis 24

5 Some Toxic Substances Associated With SRC Products 25

6 Energy Efficiency of SRC-II Systems. 46

7 Summary of Capital Costs for Conceptual SRC Plants 48

8 Required Selling Price for Investment Return - SRC-I and SRC-II Modes. 49

9 Run of Mine (ROM) Illinois No. 6 Coal Analysis 61

10 Average Ash Analysis of Illinois No. 6 Coal 61

11 Trace Element Composition of Illinois No. 6 Coal Samples 62

12 Composition of Liquefaction Reactor Product Slurry 67

13 Typical Constituents in Raw Water From The Wabash River 91

14 DOE SRC Contracts and Subcontracts Having Published Reports of Environmental Assessment Activities. 152

TABLES (continued)

Page

15 Primary and Secondary Raw Materials Supplied to SRC Basic Unit Operations. . . . 164

16 Primary and Secondary Raw Materials Supplied to Auxiliary Processes. 165

17 Geographical Distribution of Major Coal Resources and Reserves 168

18 Average Proximate Analysis of Coal by Regions. 169

19 Ultimate Analysis of Coal by Region. 169

20 Average and Maximum Elemental Composition of All U.S. Coals For Which Data Have Been Published. 175

21 Process Streams Associated With Operations and Auxiliary Processes of SRC-II. 185

22 Process Streams Associated With Auxiliary Processes of SRC-II. 187

23 Concentration of Streams from Gas Purification and Hydrogen Production 193

24 Concentration of Atmospheric Emissions from the Off-Gas from Gas Separation 193

25 Concentration in The Acid Gas to Sulfur Recovery Process Stream. 195

26 Concentration In Wastewater Process Stream from Ammonia Stripping 195

27 Wastewater From Phase Gas Separation 195

28 SRC-II Product and By-Product Terminology. . 197

29 Partitioning Factors and Estimated Concentration of Inorganics in SRC-I Light Oil-Naphtha. 199

TABLES (continued)

		Page
30	Partitioning Factors and Estimated Concentration of Inorganics in SRC-I Wash Solvent.	200
31	Partitioning Factors and Estimated Concentration of Inorganics in SRC-I Filter Cake .	201
32	Partitioning Factors and Estimated Concentration of Trace Elements in SRC Sulfur By-Products.	202
33	Element Concentrations in Process Streams as Detected by Spark Source Mass Spectroscopy (ppm)	203
34	Inorganic Element Content in Liquid Samples from Coal Liquefaction - Refined Solid . . .	206
35	Analysis of SRC-I Organics for PAH and Neutral Fractions.	208
36	Flue Gases from Auxiliary Processes.	210
37	Estimate of Inorganic Composition of Atmospheric Emission After Control of Coal Dust from Coal Pretreatment Module	213
38	Composition of Fly Ashes from Different (Unspecified) Locations Across the United States	221
39	Concentrations and Concentration Trends With Decreasing Fly Ash Particle Size for Selected Elements.	222
40	Concentration of Trace Elements in Coal and Fly Ash in Different Geographical Locations.	223
41	Enrichment Factors for Fly Ash/Coal From Unspecified Geographical Locations	225

TABLES (continued)

Page

42 Summary of Enrichment Factors. 227

43 Estimated Elemental Composition of Boiler Flue Gas Due to Fly Ash Component. 228

44 Emissions After Treatment of Stretford Tail Gas by Direct Flame inceration. 232

45 Chemical Wastes Characteristics of Coal Pile Drainage. 235

46 Wastewater Composition from Hydrotreating Module (Decanter Wastewater) 237

47 Quantified Sources and Composition of Wastewater 238

48 Characterization of Foul Process Water . . . 238

49 Characteristics of Ash Pond Effluent from Coal-Fired Power Plants Run on Kentucky Bituminous or Illinois Coal. 242

50 Effects on Refuse Pile Runoff on Stream Composition. 243

51 Organic Constituents of Bio-Unit Effluent. . 249

52 Partitioning Factors and Estimated Concentration of Inorganics in SRC Wastewater. . . 251

53 Summary of Removal of Metals by Chemical Clarification and Carbon Adsorption. 250

54 Organics Quantified in SRC-I Filter Cake Residue from Kentucky Bituminous Coal. . . . 254

55 Partitioning Factors and Estimates of Inorganic Constituents in SRC-II Mineral Residue Filter Cake. 255

56 Absorbent Purge from the Stretford Unit. . . 257

57 Characteristics of Scrubber Sludge Generated in Coal-Fired Power Plants. 261

58 Composition of Fly Ash from Average and Maximum U.S. Coals. 263

TABLES (continued)

Page

59 Estimated Inorganics in Gasifier Slag. . . . 266

60 Low Temperature Acid Gas Removal Processes . 277

61 Summary of Air Emissions Control Technology Applicability to SRC Systems 292

62 Summary of Water Effluents Control Technology Applicability to SRC Systems. 295

63 Summary of Solid Wastes Control Technology Applicability to SRC Systems 299

64 Summary of Wastewater Treatment Options for SRC-II. 303

65 Costs of Control Alternatives for Fugitive Dust 308

66 Cost of Treatment Alternatives for Control of Dust from Coal Sizing 310

67 Cost of Control Alternatives for Stack Gas from Coal Drying 310

68 Estimated Costs for Flare System of A 7,950 Mg/day SRC Plant 312

69 Costs, Efficiencies and Final Emissions for Commercially Available SO_2 Wet Scrubbing Processes. 313

70 Treatment Alternatives for Stretford Tail Gas 314

71 Tailings Pond. 316

72 Costs of Wastewater Treatment Processes for SRC Systems. 317

73 Ranking of the Materials Addressed by the Current MEG's According to Potential Environmental Hazard 329

TABLES (continued)

Page

74 Epidemiological Mortality/Morbidity Studies .334

75 Adjusted Ordering Numbers for Several Inorganics and Organics. 341

76 EPA Level 1 Bioassays 361

77 Chemicals for Which Evidence Exists of Carcinogencity to Both Nonhuman and Human Animals 371

78 Relationship Between Predicted and Actual Behavior of Human Carcinogens 373

79 National Primary and Secondary Ambient Air Quality Standards 380

80 Federal New Source Performance Standards of Coal Liquefaction-Related Technologies . .382

81 PSD Permitting Agreements 386

82 Major Stationary Sources Subject to PSD Review 388

83 National Primary and Secondary Ambient Air Quality Standards Compared to State Standards .392

84 Summary of State Ambient Air Quality Standards for Which No National Standards Exists. 393

85 Regulated Air Pollutants Which May Exceed Unknown Standards and/or May Cause Health Or Environmental Hazard 403

86 Suggestsions for More Stringent Mates for Regulated Air Pollutants. 409

87 SAM/IA Analysis of Atmospheric Emissions of Coal Pretreatment and Fly Ash from Steam Generation .410

TABLES (continued)

		Page
88	SAM/IA Analysis of Atmospheric Emissions from Treated Stretford Tail Gas, Oxygen Generation and Flare.	411
89	Unregulated Air Pollutants Which May Cause Health or Environmental Hazard.	413
90	Suggestions for More Stringent Mates for Unregulated Air Pollutants.	412
91	Summary of Federal and Selected State Water Quality Standards and Criteria.	415
92	Toxic Pollutants - List of 129 Unambiguous Priority Pollutants, Including the 65 Classes Of Toxic Chemicals.	418
93	EPA Effluent Standards for Coal Liquefaction Related Technologies.	421
94	Numerical Effluent Standards of Coal-Producing States.	434
95	Regulated Water Pollutants Which May Cause Standards and/or Which May Cause Health or Environmental Hazard	443
96	Regulated Water Pollutants for Which The Predicted Environmental Hazard May Be Too Low.	447
97	SAM/IA Analysis of Aqueous Effluent of the Hydrotreating Module, Phenol Recovery Module, and Bio-Unit.	448
98	SAM/IA Analysis of Aqueous Effluent from Coal Pile Drainage, Ash Pond Effluent, and Wastewater	449
99	Amount and Hazard Expected from Unregulated Pollutants.	451
100	Existing State Requirements for Hazardous and Solid Wastes.	455

TABLES (continued)

Page

101 Analysis Chart for Waste Groups. 458

102 IEPA Acceptable Disposal Methods 460

103 Unregulated Solid Wastes Which May Cause Environmental Hazards. 469

104 SAM/IA Analysis of Solid Wastes From The Inorganic Fraction of the Solid Residue, API Separator Bottoms, Biosludge 473

105 Pollutants for Which The SAM/IA Method May Underestimate the Environmental Hazard . . . 474

106 Concentrations of Constituents Identified In SRC Products 491

107 Comparison of Combustion Emissions to Standards for Solid Fossil Fuel-Fired Steam Generators 496

108 Comparison of Inorganic Air Emissions -- Coal Vs. SRC 497

109 Comparison of SRC Air Emissions With MEG's . 499

110 Comparison of Combustion Emissions To Standards for Liquid Fossil Fuel-Fired Steam Generators 501

111 Estimated Concentrations of Inorganics in SRC-I Light Oil Naphtha 504

112 Estimated Inorganic Concentrations in SRC-I Wash Solvent 505

113 Estimated Inorganic Concentrations in SRC-I Heavy Oil. 506

114 Estimated Inorganic Concentrations in SRC-I Filter Cake. 507

115 Estimated Inorganic Concentrations in SRC Sulfur By-Product. 508

TABLES (continued)

Page

116 Summary Derived from SAM/IA Methodology Applied to Spark Source Results from Product Streams and Residue. 509

117 Trace Elements Exceeding Health or Ecological MATE Concentrations in the Heavy Distillates. 510

118 Summary of SAM/IA For Middle and Heavy Distillates. 511

119 Radiation Protection Guides. 523

120 Estimation of the Maximum Amount of Radon Associated with 28,123 MG of the Most Radioactive Coal Known in the United States. 525

121 Summary of Individual Pollutants Which May Be Hazardous in the Individual Aqueous Waste Streams from The Conceptualized SRC Facility 539

122 Pollutants Which Are Likely to Be Hazardous in the Individual Solid Waste Streams. . . . 540

123 Inorganic Elements in SRC-I Product Streams Having SAM/IA Analysis Potential Degree of Hazards Greater Than "1" 543

124 Total Commitment of Construction Materials . 548

125 Estimated Maximum Annual Coal Consumption By Synfuels Plants by The Year 2000. 548

126 Technical Availability of Commercial SRC System Components. 566

127 DOE Contractors and Subcontractors 574

128 Efficiency of Cyclones 635

129 Air-To-Cloth Ratios for Coal Dust. 643

130 Characteristics of Filter Fabrics. 644

TABLES (continued)

Page

131 Efficiency of Scrubbers at Various Particle Sizes. 646

132 Applicability of Various Wet Scrubbers to Coal Dusts and Fly Ash. 647

133 Combustion Temperatures in Direct-Fired and Catalytic Afterburners. 648

134 Sulfur Dioxide Control Alternatives 659

135 Processes For Water Effluent Control. 663

136 Neutralization Reagents 670

137 Gravity Oil-Water Separator Design Equations. 673

138 Air Flotation Unit Operating Conditions . . . 676

139 Dissolved Air Flotation 678

140 Biological Treatment Systems. 680

141 Filtration Processes. 682

142 Removal Efficiency of Ion Exchange. 690

143 Solids Treatment. 694

144 Design Parameters for Thickeners. 696

145 Characteristics of Centrifuges. 698

146 Wet Air Oxidation Process Operating Condition. 706

147 Wet Oxidation Process 709

148 Incinceration 711

149 Composting. 717

TABLES (continued)

		Page
150	Sorbents Relative Effectiveness and Costs. .	738
151	Effects Observed for Temperature Variations Used During Fossil Fuel Processing or Conversion.	752
152	End Impacts Associated With A High-Btu Gasification Plant	756
153	Pennsylvania Standards for Contaminants. . .	759
154	Applicable Air Pollution Regulations in West Virginia.	759
155	Standards of Performance for Petroleum Refineries in Kentucky	760
156	Applicable Illinois Emissions Regulations. .	760
157	New Mexico Emissions Standards for Commercial Gasifiers.	761
158	New Mexico Emissions Standard for Refineries.	763
159	Texas Emissions Limits for Fossil Fuel Burning Steam Generators	763
160	Standards of Performance for Petroleum Refineries in Colorado	764
161	Selected South Dakota Industrial Emissions Standards.	764
162	Applicable Wyoming Emissions Regulations . .	765
163	Arizona Air Quality Goals.	765
164	Industrial Emissions Standards in Arizona. .	766
165	Emissions Standards for Industrial Processes and Fuel Burning Equipment in Alaska	766

TABLES (continued)

Page

166 Specific Water Quality Standards - Receiving Waters. 771

167 Most Stringent Water Quality Standards. . . . 772

168 Contaminants and Concentrations Not To Be Exceeded in Any Effluent. 775

169 State Land Use Programs 779

170 Interactions of Selected Elements in Soils. . 798

171 Environmental Impact Analysis - Most Significant Impacts. 801

LIST OF ABBREVIATIONS

AQCR	Air Quality Control Regions
CEC	Cation exchange capacity
cm	Centimeter
COD	Chemical oxygen demand
DCF	Discounted cash flow
DES	Diethylstilbestrol
DOE	Department of Energy
dscm	Dry standard cubic meter
DO	Dissolved oxygen
DAF	Dissolved air flotation
EAR	Environmental Assessment Report
EPRI	Electric Power Research Institute
ETTA	Effluent transport and transformation analysis
EPA	Environmental Protection Agency
GCMS	Gas chromatography/mass spectrometry
HPOAS	High purity oxygen activated sludge
HAI	Hittman Associates, Inc.
IUPAC	International Union of Pure and Applied Chemistry
IERL/RTP	Industrial Environmental Research Laboratory Research Triangle Park
kg	Kilogram
l	liter
LPG	Liquefied petroleum gas
m	Meter
μg	Microgram

MATE	Minimum acute toxicity effluent
MEA	Monoethanolamine
MEG	Multimedia environmental goal
MPa	Megapascals
Mg	Megagram
MW	Megawatt
NA	Nonattainment
NASQAN	National Stream Quality Accounting Network
OCR	Office of Coal Research
P&M	Pittsburg and Midway Coal Mining Company
PAH	Polynuclear Aromatic Hydrocarbon
PDU	Process development unit
PSD	Prevention of significant deterioration
PVC	Polyvinyl chloride
ROM	Run of mine
SSAM	Second source analysis model
scm	Standard cubic meter
SNG	Substitute natural gas
SRC-I	Solvent Refined Coal-I
SRC-II	Solvent Refined Coal-II
TDS	Total dissolved solids
TOC	Total organic carbon
ZAD	Zero aqueous discharge

NOMENCLATURE

Environmental Assessment Report: An evaluation of air emissions, water effluents, solid waste, toxic substances, control/disposal alternatives, environmental regulatory requirements and environmental effects associated with a given energy process; in this case, the Solvent Refined Coal liquefaction process.

MEG (Multimedia Environmental Goal): Levels of significant contaminants or degradents (in ambient air, water or land) that are judged to be (1) appropriate for preventing certain negative effects in the surrounding populations or ecosystems, or (2) representative of control limits achievable through technology.

MATE (Minimum Acute Toxicity Effluent): Concentration levels of contaminants in air, water or solid waste effluents that will not produce significant harmful responses in exposed humans or the ecology, provided the exposure is of limited duration. MATEs are average daily concentrations.

SAM (Source Analysis Model): A methodology which allows the identification of possible problem areas where a suspected pollutant exceeds the MEG.

SRC System: A noncatalytic direct-hydrogenation coal liquefaction process for converting high-sulfur and ash coal into clean burning gaseous, liquid or solid fuels.

SRC-I Product: A solid coal like product of less than one (1) percent sulfur and 0.2 percent ash.

SRC-II Product: A low-sulfur fuel oil of 0.2 to 0.5 percent sulfur, and naphtha product.

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1.0 SUMMARY

As part of its overall goal of maintaining a healthy environment, the United States Environmental Protection Agency's (USEPA) Industrial Environmental Research Laboratory at Research Triangle Park (IERL/RTP), North Carolina is directing an effort to evaluate the environmental aspects of emerging coal conversion technologies. Hittman Associates, Incorporated (HAI) is a prime contractor to IERL/RTP, responsible for environmental analysis of coal liquefaction systems. Environmental Assessment Reports (EAR) were developed to provide best available environmental assessment data on specified coal conversion systems in a standardized format, thereby facilitating utilization by EPA personnel and other researchers in the field. This EAR addresses Solvent Refined Coal (SRC) liquefaction systems.

Solvent Refined Coal (SRC) systems convert high sulfur and ash coal into cleaner-burning gaseous, liquid and/or solid fuels by noncatalytic direct hydrogenation. There are two basic system variations: (1) SRC-I, which produces a solid, coal-like primary product of less than 1.0 percent sulfur and 0.2 percent ash by weight; and (2) SRC-II, which produces low sulfur fuel oil (0.2 to 0.5 percent sulfur by weight) and naphtha as primary products. Both system variations produce significant quantities of gaseous hydrocarbons, which are further processed yielding substitute natural gas (SNG) and liquefied petroleum gas (LPG) products. Some constituents formed during coal hydrogenation may be recovered as by-products, including sulfur, ammonia, and phenols.

1.1 Overview of Solvent Refined Coal Systems

Solvent Refined Coal (SRC) is currently being developed by the Pittsburg and Midway Coal Mining Company (P&M), part of Gulf Oil Corporation, under sponsorship of the U.S. Department of Energy. The concept of solvent refining in this country originated with the Spencer Chemical Company in 1962. Acquisition of Spencer Chemical Company by Gulf Oil Corporation transferred development responsibility to P&M.

Much of the early development work was performed in bench-scale units such as those at the P&M research facilities in Merriam, Kansas. Subsequent contracts were negotiated with the Office of Coal Research (OCR) for the design, construction and operation of an SRC pilot plant. The pilot plant, located in Fort Lewis, Washington, became fully operational in 1974. The 45.5 Mg (50 tons)/day coal feed capacity pilot plant was designed by Stearns-Roger Corporation and built by Rust Engineering Company.

During its four years of operation the Fort Lewis pilot plant has permitted numerous technical achievements. Process variable studies have examined the effects of varying coal feed rates and reactor temperatures on SRC system operations. About 2700 Mg (3000 tons)/day of SRC-I product (solid at ambient conditions) were produced for combustion testing. SRC-II, an alternate mode of operation yielding products that are liquid at ambient conditions was tested successfully. SRC-II yields were also produced in large quantities (about 800 m^3) for combustion testing. A number of alternative methods for solids/liquids separation were tested. In addition most of the operating problems associated with pilot plant startup have been solved, permitting generally reliable operation of the facility.

In addition to the Fort Lewis pilot plant, a 5.5 Mg (6 tons)/day coal feed capacity pilot plant was built in Wilsonville, Alabama. The Wilsonville facility is operated by Catalytic, Inc. under sponsorship of the Electric Power Research Institute (EPRI). The Wilsonville facility has operated only in the SRC-I (solid product) mode. Table 1 lists some noteworthy SRC milestones.

1.1.1 SRC-II Liquefaction

SRC systems are defined to consist of the following system operations, which perform specific functions essential to solvent refining:

- Coal pretreatment - preparation of the coal feed to meet system specifications for size and moisture content.
- Coal liquefaction - reaction of feed coal with hydrogen, yielding a three-phase mixture of increased liquid and gaseous hydrocarbon content.
- Separation - includes all necessary phase separations. Gas separation and solids/liquids separation processes are employed in SRC systems.
- Purification and upgrading - a fractionation process is used to separate components of the raw liquid products mixture by distillation, due to differences in boiling points. A hydrotreating process may be optionally employed to upgrade the quality of fractionated product liquids.

TABLE 1. KEY EVENTS IN THE DEVELOPMENT OF SOLVENT REFINED COAL SYSTEMS INCLUDING PROJECTED PLANS

1960	
	1962: OCR awards research contract to Spencer Chemical Company.
1965	1965: Solvent refining successfully demonstrated in 22.7 kg (50 lb)/hr continuous flow unit.
	1969: Stearns-Roger Corporation completes design of 45.5 Mg (50 ton)/day Fort Lewis pilot plant.
1970	
	1972: OCR/P&M contract extended for pilot plant construction and evaluation; Rust Engineering begins construction.
	1973: Construction of Wilsonville pilot plant.
1975	1974: Both pilot plants become fully operational.
	1975: Fort Lewis process variable studies, SRC-I production runs for combustion testing.
	1977: Fort Lewis plant modified, begins SRC-II production; SRC-I combustion test.
	(1978: SRC-II combustion test; DOE awards design contracts for SRC-I and SRC-II demonstration plants.
1980	
	1983: Projected startup of demonstration plants
1985	
	1987: Projected startup date of commercial SRC plants.
1990	

A fully integrated SRC-II (liquid product) system flow scheme is shown in Figure 1. Raw coal from coal storage facilities is sent to the coal pretreatment operation where it is sized, dried and mixed with reactor product slurry recycled from the gas separation process. The resulting feed slurry is combined with recycle hydrogen from the hydrogen/hydrocarbon recovery process and makeup hydrogen from the hydrogen production process. The hydrogen-rich slurry is pumped through a preheater to the liquefaction reactor, or dissolver. Exothermic hydrogenation reactions initiated in the preheater continue in the dissolver which typically operates between 435 and 470°C. The reactor product slurry is sent to the gas separation process which removes gaseous products of the hydrogenation reactions. Various auxiliary processes recover valuable constituents from the separated mixture of gases including recycle hydrogen, SNG, LPG, and sulfur species which are converted to by-product elemental sulfur. Part of the separated slurry from gas separation is recycled to the coal pretreatment operation. The remainder of the slurry, along with condensed oils produced during gas separation, is sent to the fractionator. The fractionator generates three streams: a light distillate which is hydrotreated to form naphtha and fuel oil products; liquid SRC, the primary product; and a bottom stream which is sent to the solids/liquids separation process. The vacuum distillation unit in solids/liquids separation recovers additional SRC liquid product from the fractionator bottoms, yielding a residue of high mineral matter content. This residue is gasified in the hydrogen generation auxiliary process to produce makeup hydrogen for the liquefaction operation.

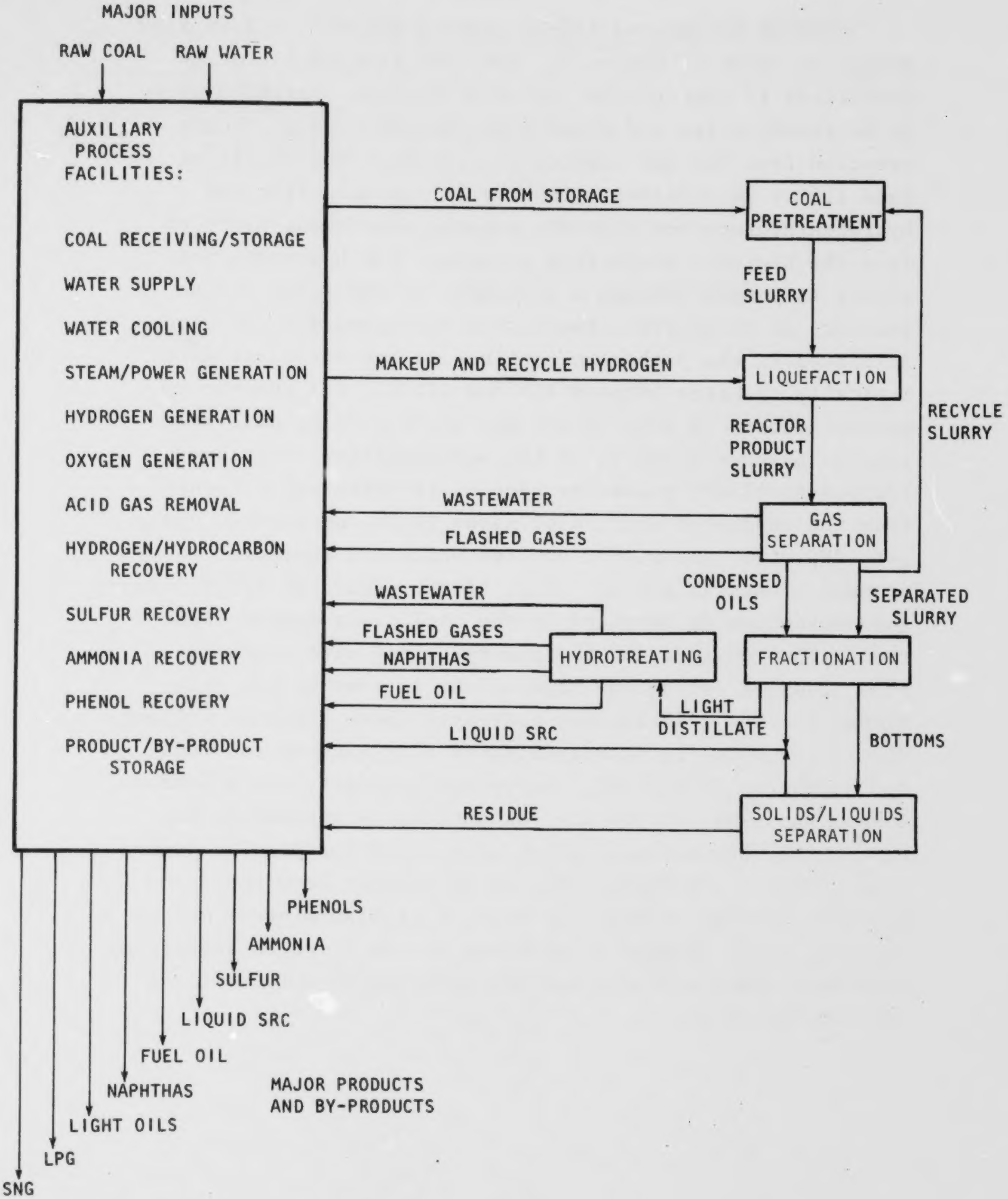
MAJOR INPUTS
RAW COAL
RAW WATER
AUXILIARY PROCESS FACILITIES:
COAL RECEIVING/STORAGE
WATER SUPPLY
WATER COOLING
STEAM/POWER GENERATION
HYDROGEN GENERATION
OXYGEN GENERATION
ACID GAS REMOVAL
HYDROGEN/HYDROCARBON RECOVERY
SULFUR RECOVERY
AMMONIA RECOVERY
PHENOL RECOVERY
PRODUCT/BY-PRODUCT STORAGE
COAL FROM STORAGE
COAL PRETREATMENT
FEED SLURRY
MAKEUP AND RECYCLE HYDROGEN
LIQUEFACTION
RECYCLE SLURRY
REACTOR PRODUCT SLURRY
WASTEWATER
GAS SEPARATION
FLASHED GASES
CONDENSED OILS
SEPARATED SLURRY
WASTEWATER
FLASHED GASES
NAPHTHAS
HYDROTREATING
FRACTIONATION
FUEL OIL
LIGHT DISTILLATE
LIQUID SRC
BOTTOMS
RESIDUE
SOLIDS/LIQUIDS SEPARATION
PHENOLS
AMMONIA
SULFUR
LIQUID SRC
FUEL OIL
NAPHTHAS
LIGHT OILS
LPG
SNG
MAJOR PRODUCTS AND BY-PRODUCTS

Figure 1. SRC-II system

1.1.2 SRC-I Liquefaction

The SRC-I (solid product) mode is illustrated in Figure 2. Raw coal is sized and dried as in SRC-II. However, the prepared coal is mixed with a recycle solvent recovered in the fractionation process rather than slurry from the gas separation operation as is done in the SRC-II system. Slurry preheating, liquefaction, and gas separation proceed as described for the SRC-II mode. Condensed oils recovered during gas separation are sent directly to the hydrotreating process for upgrading to naphtha and fuel oil. (Note that in the SRC-II system condensed oils are sent to fractionation.) The separated slurry from the gas separation process is sent to solids/liquids separation. Filtration is the most likely process to be employed in the SRC-I system for solids/liquids separation, however alternate approaches such as solvent deashing and centrifugation have been suggested. Filter cake produced during filtration is sent to the hydrogen generation process where it is gasified to provide makeup hydrogen. Filtered product liquids are sent to the fractionation process. (Note that fractionation precedes solids/liquids separation in SRC-II.) Fractionation of the filtered product liquids yields three outputs: a solvent fraction, which is recycled to coal preparation for slurrying with feed coal; a wash solvent recycled to the filtration unit in solids/liquids separation; and SRC-I product which is cooled and stored as a solid. The SRC-I system consumes all light fractions (SNG and LPG) produced; hence, these commodities are not available as saleable products.

1.1.3 Auxiliary Processes in SRC Systems

The following auxiliary processes are required for either supply of input materials or recovery of by-products

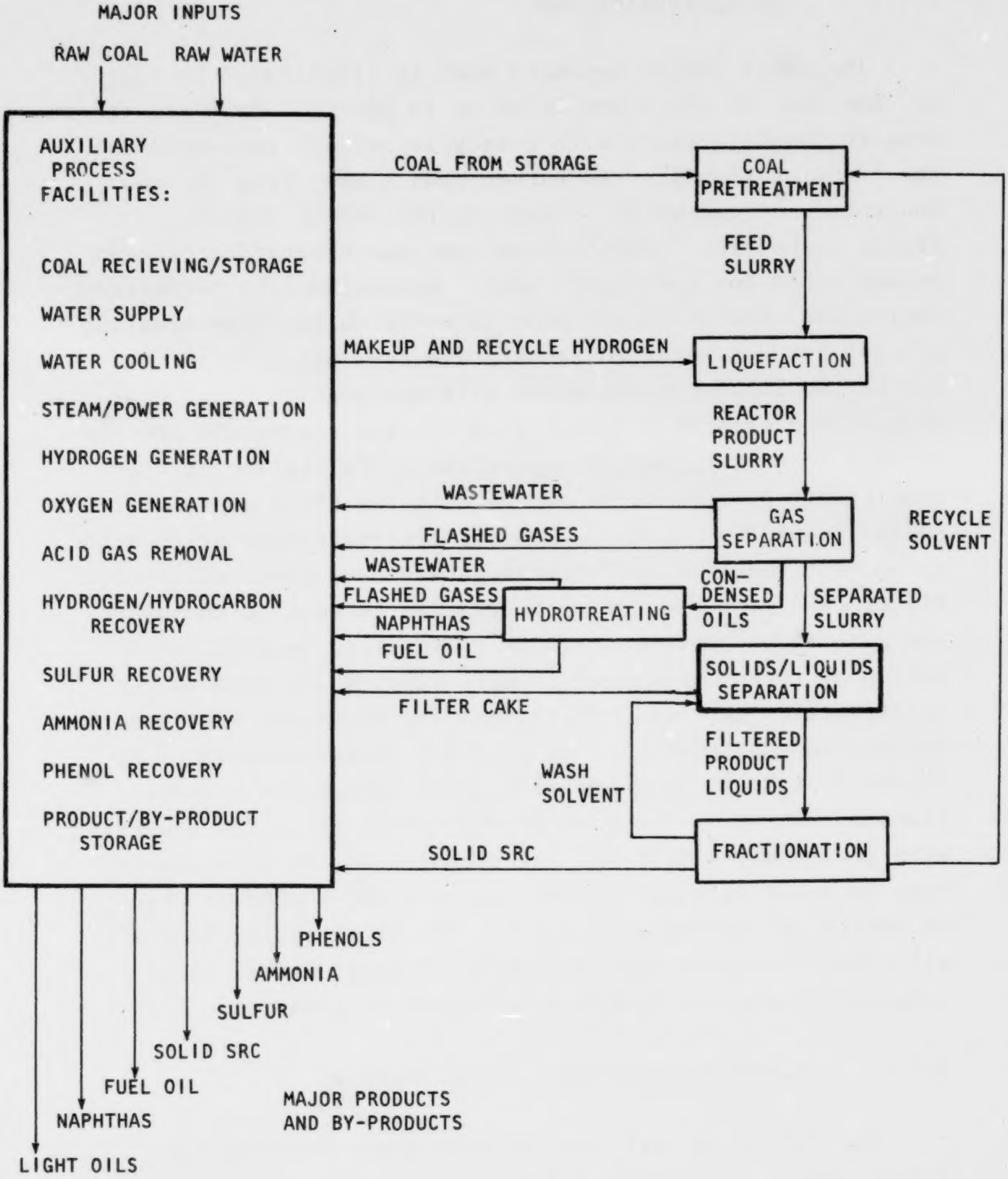
MAJOR INPUTS
RAW COAL
RAW WATER
AUXILIARY PROCESS FACILITIES:
COAL RECIEVING/STORAGE
WATER SUPPLY
WATER COOLING
STEAM/POWER GENERATION
HYDROGEN GENERATION
OXYGEN GENERATION
ACID GAS REMOVAL
HYDROGEN/HYDROCARBON RECOVERY
SULFUR RECOVERY
AMMONIA RECOVERY
PHENOL RECOVERY
PRODUCT/BY-PRODUCT STORAGE
COAL FROM STORAGE
COAL PRETREATMENT
FEED SLURRY
MAKEUP AND RECYCLE HYDROGEN
LIQUEFACTION
REACTOR PRODUCT SLURRY
WASTEWATER
FLASHED GASES
GAS SEPARATION
RECYCLE SOLVENT
WASTEWATER
FLASHED GASES
NAPHTHAS
FUEL OIL
HYDROTREATING
CON-DENSED OILS
SEPARATED SLURRY
SOLIDS/LIQUIDS SEPARATION
FILTER CAKE
FILTERED PRODUCT LIQUIDS
WASH SOLVENT
FRACTIONATION
SOLID SRC
PHENOLS
AMMONIA
SULFUR
SOLID SRC
FUEL OIL
NAPHTHAS
LIGHT OILS
MAJOR PRODUCTS AND BY-PRODUCTS

Figure 2. SRC-I system

in SRC systems: coal receiving and storage, water supply, water cooling, steam and power generation, hydrogen generation, oxygen generation, acid gas removal, hydrogen/hydrocarbon recovery, sulfur recovery, ammonia recovery, phenol recovery, and product/by-product storage. The role of auxiliary processes is shown in Figure 3 and discussed below in brief.

- Coal Receiving and Storage. Raw coal is typically delivered by rail or truck. The coal receiving and storage facilities stockpile raw coal until it is required by the coal pretreatment operation.

- Water Supply. This auxiliary process prepares raw water for use in SRC system operations and other auxiliary processes such as water cooling, steam and power generation, and hydrogen generation.

- Water Cooling. Water cooling provides cooling water for heat exchange applications in SRC system operations and auxiliary facilities including gas separation and steam and power generation.

- Steam and Power Generation. Electrical power is consumed throughout the liquefaction plant. Steam is used in heat transfer applications.

- Hydrogen Generation. Mineral residue (SRC-II mode) or filter cake (SRC-I mode) is reacted in a coal gasifier to provide makeup hydrogen to the liquefaction operation and hydrotreating process.

- Oxygen Generation. Oxygen generation recovers an oxygen-rich fraction from air for use in the hydrogen generation gasifier. (Oxygen production

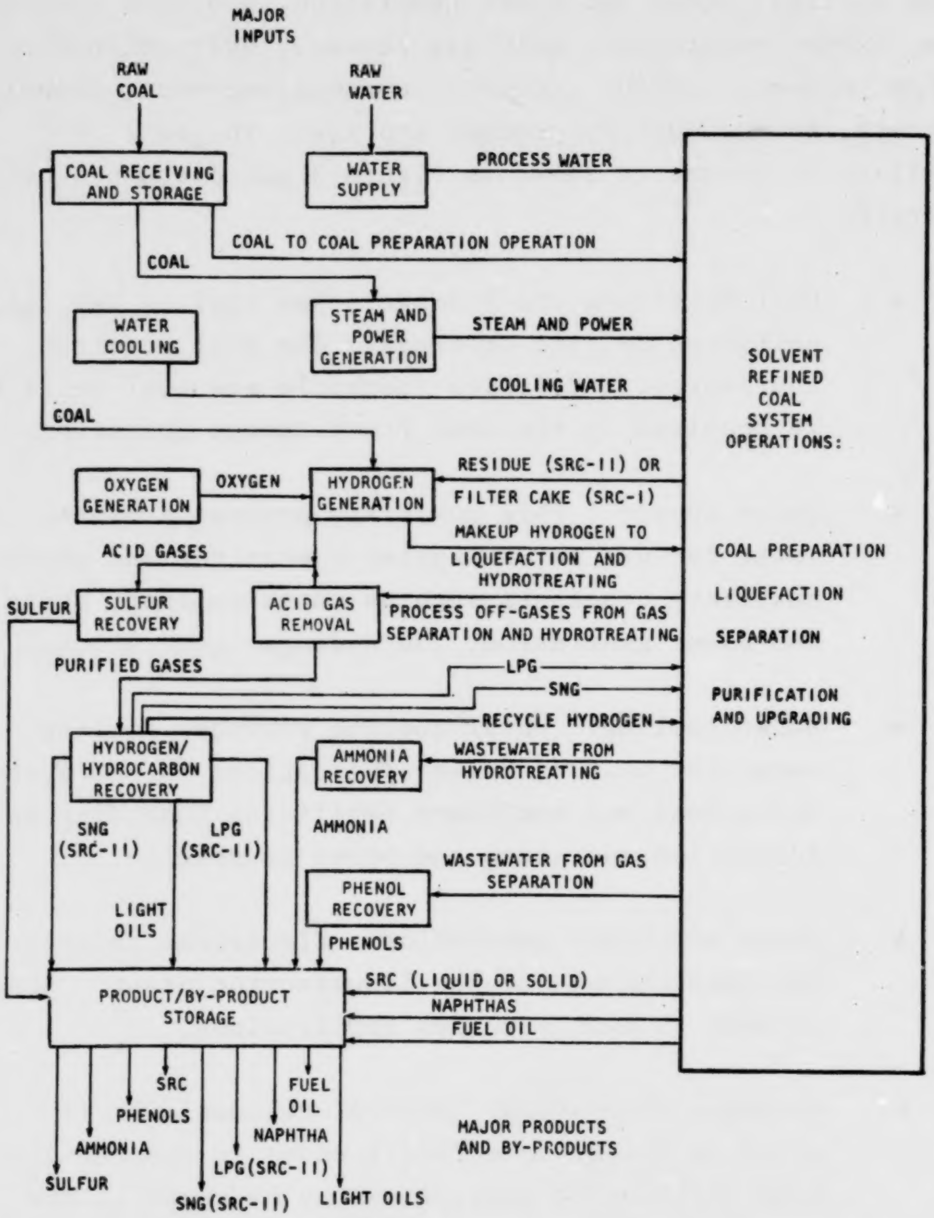
MAJOR INPUTS
RAW COAL
RAW WATER
COAL RECEIVING AND STORAGE
WATER SUPPLY
PROCESS WATER
COAL TO COAL PREPARATION OPERATION
COAL
STEAM AND POWER GENERATION
STEAM AND POWER
WATER COOLING
COOLING WATER
COAL
SOLVENT REFINED COAL SYSTEM OPERATIONS:
COAL PREPARATION
LIQUEFACTION
SEPARATION
PURIFICATION AND UPGRADING
OXYGEN GENERATION
OXYGEN
HYDROGEN GENERATION
RESIDUE (SRC-II) OR
FILTER CAKE (SRC-I)
MAKEUP HYDROGEN TO LIQUEFACTION AND HYDROTREATING
ACID GASES
SULFUR
SULFUR RECOVERY
ACID GAS REMOVAL
PROCESS OFF-GASES FROM GAS SEPARATION AND HYDROTREATING
PURIFIED GASES
LPG
SNG
RECYCLE HYDROGEN
HYDROGEN/HYDROCARBON RECOVERY
AMMONIA RECOVERY
WASTEWATER FROM HYDROTREATING
SNG (SRC-II)
LPG (SRC-II)
AMMONIA
LIGHT OILS
PHENOL RECOVERY
WASTEWATER FROM GAS SEPARATION
PHENOLS
PRODUCT/BY-PRODUCT STORAGE
SRC (LIQUID OR SOLID)
NAPHTHAS
FUEL OIL
SRC
FUEL OIL
PHENOLS
NAPHTHA
AMMONIA
LPG(SRC-II)
SULFUR
SNG(SRC-II)
LIGHT OILS
MAJOR PRODUCTS AND BY-PRODUCTS

Figure 3. Auxiliary processes in SRC systems

would not be necessary for hydrogen production by an air-fired gasifier).

- Acid Gas Removal. Gases produced during liquefaction and hydrogen production reactions contain sulfur bearing constituents. Acid gas removal separates these constituents and carbon dioxide from gas mixtures.

- Sulfur Recovery. Sulfur recovery converts sulfur-bearing acid gas constituents to elemental sulfur, which is stored as a by-product.

- Hydrogen/Hydrocarbon Recovery. Purified gases from acid gas removal contain significant amounts of hydrocarbons and unreacted hydrogen. Using cryogenic separation techniques this process recycles hydrogen to liquefaction and hydrotreating. Hydrocarbons are recovered as SNG and LPG which are used in system operations and auxiliary processes. Operation in the SRC-II mode produces excess SNG and LPG which are stored as products.

- Ammonia Recovery. This process removes by-product ammonia from process wastewater before wastewater treatment.

- Phenol Recovery. Phenol recovery removes by-product phenols from process wastewater prior to wastewater treatment.

- Product/By-Product Storage. This area holds products and by-products of SRC systems until they may be distributed for marketing.

1.2 Waste Streams and Pollutants of Major Concern

1.2.1 Waste Streams to Air

As shown in Figure 4, air emissions are associated with a majority of the operations and auxiliary processes which comprise SRC systems. Air emissions specific to operation in the SRC-I or SRC-II mode are noted. In addition to the air emissions sources shown, fugitive emissions, such as vapor leaks from pressurized process equipment may occur in SRC systems. An overview of emissions shown in the figure is given below.

- Flue gases - flue gases are produced by combustion units (primarily preheaters) in the following system operations and auxiliary processes: liquefaction, separation, purification and upgrading, hydrogen generation and sulfur recovery. Assuming the SNG and LPG products are used as fuel in these units, minimal environmental effects are anticipated.

- Coal dust - coal handling, processing and storing in coal receiving and storage and coal pretreatment results in particulate coal dust entering the atmosphere. Composition of the dust is the same as that of the raw coal.

- Dryer stack gas - in order to conform to system feed specification for moisture content, feed coal is dried in coal pretreatment operation. The stack gas produced by coal drying contains particulate coal and possibly volatilized hydrocarbons present in the raw coal.

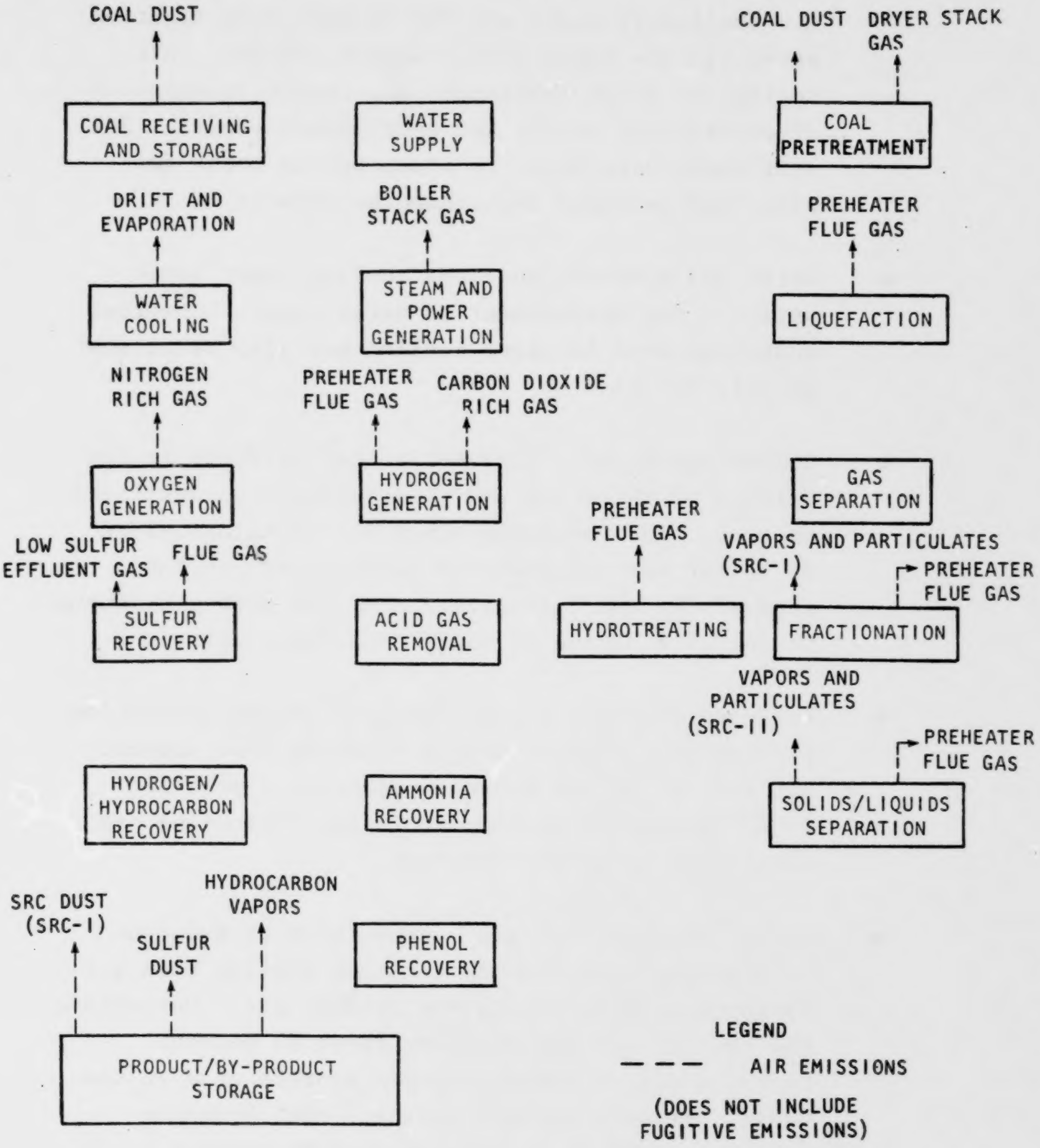
COAL DUST
COAL RECEIVING AND STORAGE
WATER SUPPLY
COAL DUST
DRYER STACK GAS
COAL PRETREATMENT
DRIFT AND EVAPORATION
WATER COOLING
BOILER STACK GAS
STEAM AND POWER GENERATION
PREHEATER FLUE GAS
LIQUEFACTION
NITROGEN RICH GAS
OXYGEN GENERATION
PREHEATER FLUE GAS
CARBON DIOXIDE RICH GAS
HYDROGEN GENERATION
GAS SEPARATION
LOW SULFUR EFFLUENT GAS
FLUE GAS
SULFUR RECOVERY
ACID GAS REMOVAL
PREHEATER FLUE GAS
HYDROTREATING
VAPORS AND PARTICULATES (SRC-I)
PREHEATER FLUE GAS
FRACTIONATION
VAPORS AND PARTICULATES (SRC-II)
PREHEATER FLUE GAS
SOLIDS/LIQUIDS SEPARATION
HYDROGEN/ HYDROCARBON RECOVERY
AMMONIA RECOVERY
SRC DUST (SRC-I)
SULFUR DUST
HYDROCARBON VAPORS
PHENOL RECOVERY
PRODUCT/BY-PRODUCT STORAGE
LEGEND
AIR EMISSIONS
(DOES NOT INCLUDE FUGITIVE EMISSIONS)

Figure 4. Air emissions from SRC system

- Vapors and particulates from cooling - mineral residue resulting from solids/liquids separation (in the SRC-II mode) and SRC product from fractionation (in the SRC-I mode) require cooling. Air cooling of these substances may result in emissions of particulate solids and hydrocarbon vapors. Insufficient data exist to characterize these emissions and estimate environmental effects.

- Drift and evaporation - the cooling tower loses water to the environment as water vapor. Chemical additives used in water cooling may also be present in this emission.

- Boiler stack gas - presumably coal is fired in the boilers of the steam and power generation auxiliary process. The resulting stack gas contains oxides of sulfur and nitrogen and particulates in the form of fly ash. Utilization of SRC system products is one alternative of minimizing these emissions.

- Nitrogen rich gas - the cryogenic oxygen generation process separates an oxygen rich gas from ambient air for use in the hydrogen generation process. Other components of the air (mainly nitrogen) are discharged as an air emission.

- Carbon dioxide rich gas - production of hydrogen by gasification produces a carbon dioxide rich gas during upgrading of the raw product gas. Untreated, the raw product gas contains about 55 percent hydrogen and 40 percent carbon dioxide on a volume basis. Process designs indicate that hydrogen makeup gas should be greater than 90 percent hydrogen on a volume basis. A two stage amine scrubber is used to remove carbon dioxide, leaving a treated hydrogen rich stream of the required purity. Gases removed in the second stage are predominantly carbon dioxide and have, in conceptual designs, been emitted directly to the atmosphere. Emission controls may need to be investigated when characterization data become available.

- Low sulfur effluent gas - sulfur bearing acid gases from hydrogen generation and SRC system operations are treated to convert sulfur gases to elemental sulfur. The resulting product gas is flared and discharged.
- SRC dust (SRC-I mode) and sulfur dust - handling and storage of SRC system solid products and by-products results in release of dust to the environment.
- Hydrocarbon vapors - liquid products of SRC systems contain volatile hydrocarbon components. Care must be exercised in handling and storage of these liquids to minimize emissions.

Analysis of existing information indicates that dust emissions from coal receiving and storage and coal preparation, low-sulfur effluent gas from sulfur recovery, boiler flue gas from steam and power generation, and the emission from the flare system should be regarded as those emissions to air of greatest environmental concern. (A flare system is used to treat hydrocarbon emissions as discussed in Sections 1.3 and 4.0). Component pollutants of concern are summarized in Table 2, based on SAM/IA analysis using health-based MATE's for evaluation of potential degree of hazard.

TABLE 2. AIR EMISSIONS OF CONCERN* ASSOCIATED WITH SRC SYSTEMS BASED ON SAM/IA ANALYSIS

Air Emission	Pollutant	Health-Based MATE, ($\mu g/m^3$)	Potential Degree of Hazard**
Particulate coal dust***	Aluminum	5200.	$2.3x10^{-3}$ -1.7***
	Arsenic	2.0	$4.9x10^{-3}$ -3.6
	Chromium	1.0	$1.5x10^{-2}$ -11.0
	Iron	1000.	$1.3x10^{-2}$ -9.9
	Lithium	22.0	$1.4x10^{-3}$ -1.1
	Silicon	$1.0x10^4$	$2.1x10^{-3}$ -1.5
Sulfur re-recovery tail gas****	Carbon dioxide	$9.0x10^6$	87.0
Boiler flue gas	Arsenic	2.0	3.0
	Carbon monoxide	$4.0x10^4$	1.3
	Chromium	1.0	7.3
	Iron	1000.	3.7
	Nitrogen oxides	9000.	56
	Sulfur dioxide	$1.3x10^4$	49
Flare system emission	Carbon dioxide		20
	Carbon monoxide	$4.0x10^4$	14

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*Based on liquefaction of "average" U.S. coal as defined in Section 3.0.

$$\text{**Potential degree of hazard} = \frac{\text{Projected air concentration } (\mu g/m^3)}{\text{Health based MATE } (\mu g/m^3)}$$

***Ranges due to different types of particulate controls employed. Low values correspond to treatment by cyclone and baghouse filter. High values correspond to treatment by venturi scrubber.

****Carbon monoxide and ammonia concentrations exceed ecological-based MATE but not health-based MATE

Two important conclusions can be drawn from Table 2. The first is that all emissions cited are associated with existing industries (coal mining, petroleum refining and steam-electric power generation). Concern with these emissions is not directly attributable to operations or auxiliary processes unique to SRC systems. Secondly, in the case of coal dust, application of the best recommended control technology (cyclone and baghouse filter - see Sections 1.3 and 4.0) reduces the potential degree of hazard values below one i.e., below the health-based MATE value.

1.2.2 Waste Streams to Water

Sources of wastewater are shown in Figure 5, and are discussed below in brief.

- Coal pile runoff - precipitation striking the raw coal in coal receiving and storage and coal preparation infiltrates the coal pile. During this contact, leaching of both organic and inorganic constituents of the raw coal occurs. Runoff water is collected for treatment.

- Thickener underflow - wastewater from the coal preparation operation is routed to a thickener. Clarified water is recycled to coal preparation. The underflow stream contains a high level of suspended solids and coal-derived organic constituents.

- Cooling tower blowdown - drift and evaporation from the cooling tower result in increased concentrations of dissolved and suspended solids in the process cooling water. A blowdown or "bleed"

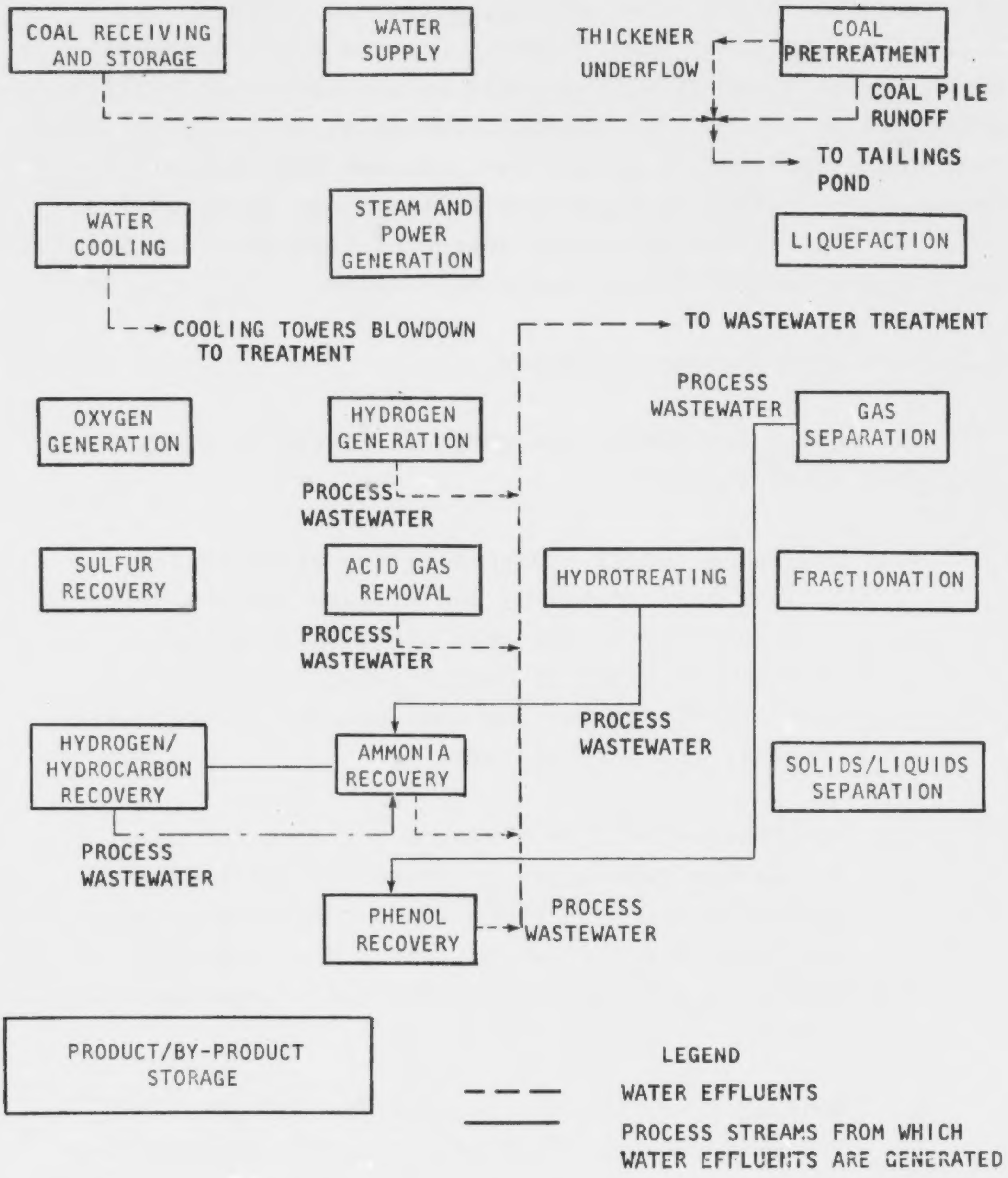

COAL RECEIVING AND STORAGE
WATER SUPPLY
THICKENER UNDERFLOW
COAL PRETREATMENT
COAL PILE RUNOFF
TO TAILINGS POND
WATER COOLING
STEAM AND POWER GENERATION
LIQUEFACTION
COOLING TOWERS BLOWDOWN TO TREATMENT
TO WASTEWATER TREATMENT
PROCESS WASTEWATER
GAS SEPARATION
OXYGEN GENERATION
HYDROGEN GENERATION
PROCESS WASTEWATER
SULFUR RECOVERY
ACID GAS REMOVAL
HYDROTREATING
FRACTIONATION
PROCESS WASTEWATER
PROCESS WASTEWATER
HYDROGEN/ HYDROCARBON RECOVERY
AMMONIA RECOVERY
SOLIDS/LIQUIDS SEPARATION
PROCESS WASTEWATER
PHENOL RECOVERY
PROCESS WASTEWATER
PRODUCT/BY-PRODUCT STORAGE
LEGEND
WATER EFFLUENTS
PROCESS STREAMS FROM WHICH WATER EFFLUENTS ARE GENERATED

Figure 5. Sources of water effluents in SRC systems

stream is withdrawn to maintain dissolved and suspended solids concentration within design specifications.

- Process wastewater from hydrogen generation - wastewater from hydrogen generation may contain tars, oils and ammonia. This stream is directed to the main wastewater treatment facility.
- Process wastewater from acid gas removal - a purge stream is removed from the amine-based acid gas removal process to maintain the concentration of amine and to remove spent amines which have formed nonregenerable compounds. This stream is directed to the main wastewater treatment facility.
- Process wastewater from ammonia recovery process - wastewaters from hydrotreating, hydrogen generation and hydrogen/hydrocarbon recovery contain significant quantities of ammonia. These wastewaters are combined and input to the ammonia recovery process. The effluent wastewater exiting ammonia recovery contains hydrogen sulfide, phenols, hydrocarbons and traces of ammonia. This stream is directed to the main wastewater treatment facility.
- Process wastewater from phenol recovery process - the gas separation operation removes gaseous constituents of the liquefaction reactor effluent. Condensation of the gases yield a phenol rich aqueous phase which is sent to the phenol recovery process. After phenol recovery the wastewater stream, containing hydrocarbons, ammonia, hydrogen sulfide and traces of phenol, is combined with

other process wastewaters (from hydrogen generation, acid gas removal and ammonia recovery) during wastewater treatment.

Coal pile runoff and effluent water from the wastewater treatment facility are considered water effluents of concern. Specific pollutants of concern are shown in Table 3. The characteristics of coal pile runoff are not a result of SRC technology; however, combined wastewater characteristics do result from SRC liquefaction.

1.2.3 Solid Wastes

Sources of solid wastes in SRC systems are shown in Figure 6. Sources and characteristics of solid wastes are described below.

- Coal cleaning refuse - refuse is a mixture of mineral matter (such as slate and tramp iron), water and coal. Refuse is recovered during coal sizing and drying.

- Excess residue (SRC-II mode) or filter cake (SRC-I) -depending on the method of hydrogen production employed in SRC systems, the possibility exists that an excess of SRC-II mineral residue or SRC-I filter cake will be produced. These solids consist of mineral matter present in the feed coal and high molecular weight hydrocarbon species.

- Spent catalysts - the hydrotreating process uses a catalyst to upgrade coal liquids. A catalyst also may be employed in the shift converter to the hydrogen generation catalyst. In order to maintain conversion efficiencies, catalysts are withdrawn periodically and replaced with fresh ones.

TABLE 3. WATER EFFLUENTS OF CONCERN* ASSOCIATED WITH SRC SYSTEMS BASED ON SAM/IA ANALYSIS

Water Effluent	Pollutant	Health-Based MATE, (μg/m3)	Potential Degree of Hazard**
Coal pile runoff	Aluminum	8.0×10^4	9.1
	Calcium	2.4×10^5	1.2
	Chromium	250.	8.0
	Iron	1500.	6000.
	Manganese	250.	272.
	Mercury	10.	1.4
	Nickel	250.	4.3
	Sulfate	1.5×10^4	170.
Combined wastewater	Bismuth	6.1×10^3	5.2
	Cresols	5.	188.
	C_3-phenols	5.	18.0
	Naphthols		60.0
	Phenol	5.	78.0
	Xylenol	5.	76.0

*Inorganics based on "average" U.S. coal as defined in Section 3.0. Organics based on characteristics of bio-unit effluent as given in Section 3.0.

$$\text{**Potential degree of hazard} = \frac{\text{Projected water concentration } (\mu g/l)}{\text{Health-based MATE } (\mu g/l)}$$

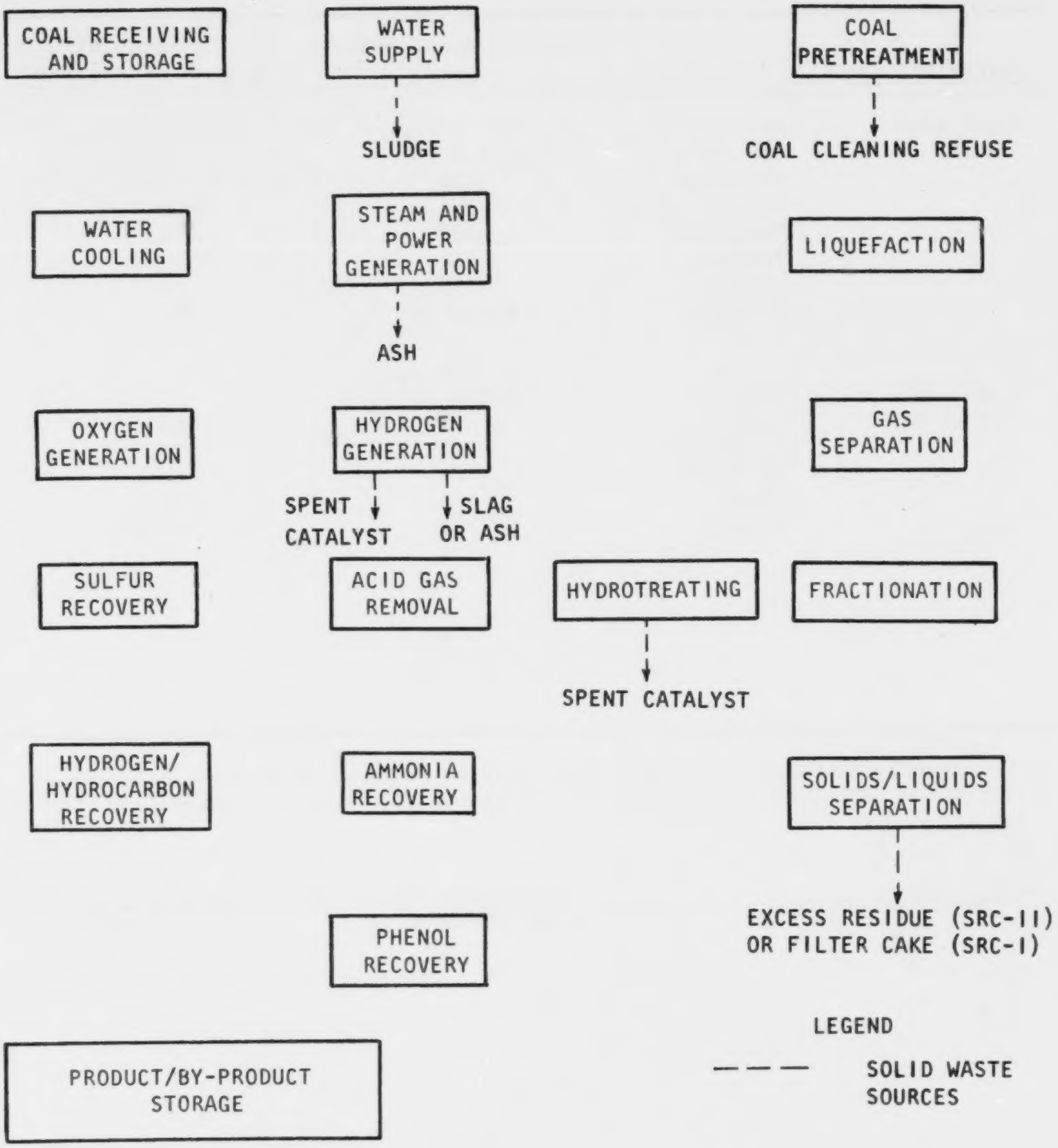

COAL RECEIVING AND STORAGE
WATER SUPPLY
SLUDGE
COAL PRETREATMENT
COAL CLEANING REFUSE
WATER COOLING
STEAM AND POWER GENERATION
ASH
LIQUEFACTION
OXYGEN GENERATION
HYDROGEN GENERATION
SPENT CATALYST
SLAG OR ASH
GAS SEPARATION
SULFUR RECOVERY
ACID GAS REMOVAL
HYDROTREATING
SPENT CATALYST
FRACTIONATION
HYDROGEN/ HYDROCARBON RECOVERY
AMMONIA RECOVERY
SOLIDS/LIQUIDS SEPARATION
EXCESS RESIDUE (SRC-II) OR FILTER CAKE (SRC-I)
PHENOL RECOVERY
LEGEND
SOLID WASTE SOURCES
PRODUCT/BY-PRODUCT STORAGE

Figure 6. Sources of solid wastes in SRC systems

- Sludge from water supply - demineralization of raw water for use in SRC systems produces a sludge. The sludge contains metal complexes, carbonate compounds, suspended solids, and other trace compounds present in the raw water.

- Ash from steam and power generation - ash is the oxidized mineral matter present in coal fed to the boilers.

- Slag or ash from hydrogen generation - gasification of mineral residue or filter cake to produce hydrogen converts mineral matter to ash. If a high temperature gasifier is used, the ash may fuse and be recovered as a slag.

Solid wastes of environmental concern, based on SAM/IA analysis with the health-based MATE's are shown in Table 4. API separator bottoms and biosludge from the wastewater treatment system and SRC mineral residues contain component pollutant species which exceed their MATE values. These solids are considered greater risks to the environment than either SRC air emissions or water effluents. It is recommended that any excess mineral residue be gasified both for additional energy recovery and to reduce the toxicity of the material (slag) which must be disposed. The gasifier slag from hydrogen generation does not exceed any of the health-based MATE's.

1.2.4 Toxic Substances

The products resulting from operation of SRC-I and SRC-II systems include substitute natural gas (SNG), liquified petroleum gas (LPG), light oils, naphthas, fuel oils, solid

TABLE 4. SOLID WASTES OF CONCERN* ASSOCIATED WITH SRC SYSTEMS BASED ON SAM/IA ANALYSIS

Solid Waste	Pollutant	Health-Based MATE (μg/g)	Potential Degree of Hazard**
SRC-II mineral residue***	Aluminum	1.6×10^4	3.7
	Arsenic	50	1.1
	Barium	1000	1.2
	Beryllium	6	1.2
	Calcium	4.8×10^4	2.2
	Cobalt	150	2.4
	Iron	300	310.
	Lead	50	1.4
	Manganese	50	4.8
	Nickel	45	2.1
	Potassium	6000	3.0
	Selenium	10	2.0
API separator bottoms	Arsenic	50	2.0
	Beryllium	6	80.0
	Cadmium	10	5.0
	Cobalt	150	250.
	Dysprosium	4.6×10^2	350.
	Lead	50	364.
	Mercury		530.
	Nickel	45	51.0
	Selenium	10	260.
Biosludge	Aluminum	1.6×10^4	1.1
	Mercury	5.0×10^1	7.0
	Vanadium	500	1.1

*Based on liquefaction of "average" U.S. coal as defined in Section 3.0.

**Potential degree of hazard = $\dfrac{\text{Projected pollutant concentration } (\mu g/g)}{\text{Health-based MATE } (\mu g/g)}$

***Similar characteristics expected for SRC-I filter cake.

and liquid solvent refined coal product, sulfur, phenols and ammonia. Existing stream characterization data indicate toxic substances to be associated primarily with the liquid products and solid SRC. In addition to organic toxics, essentially all trace elements found in the feed are also present in SRC products. Toxics identified by analysis of SRC-II product are shown in Table 5.

TABLE 5. SOME TOXIC SUBSTANCES ASSOCIATED WITH SRC PRODUCTS

Compound	Light Oil Concentration*	SRC Liquid Product Concentration*
acenaphthalene	2	8
antracene/phenanthrene	25	300
ethylbenzene	9800	not detected
fluorene	15	27
naphthalene	1630	1
pyrene	20	280

*Concentrations in parts per million (weight basis).

1.3 Status of Environmental Protection Alternatives

1.3.1 Air Emissions Controls

Air emissions control options are illustrated in Figure 7. Coal dust is generated by both storage and sizing of the coal. Spraying the storage piles with water or a polymer minimizes fugitive dust emissions. A combination of cyclones and baghouse filters is recommended to control coal dust generated by coal sizing. The coal dryer stack gas also contains particulates. A cyclone and baghouse filter in combination or a wet scrubbing device such as a venturi scrubber are applicable control alternatives.

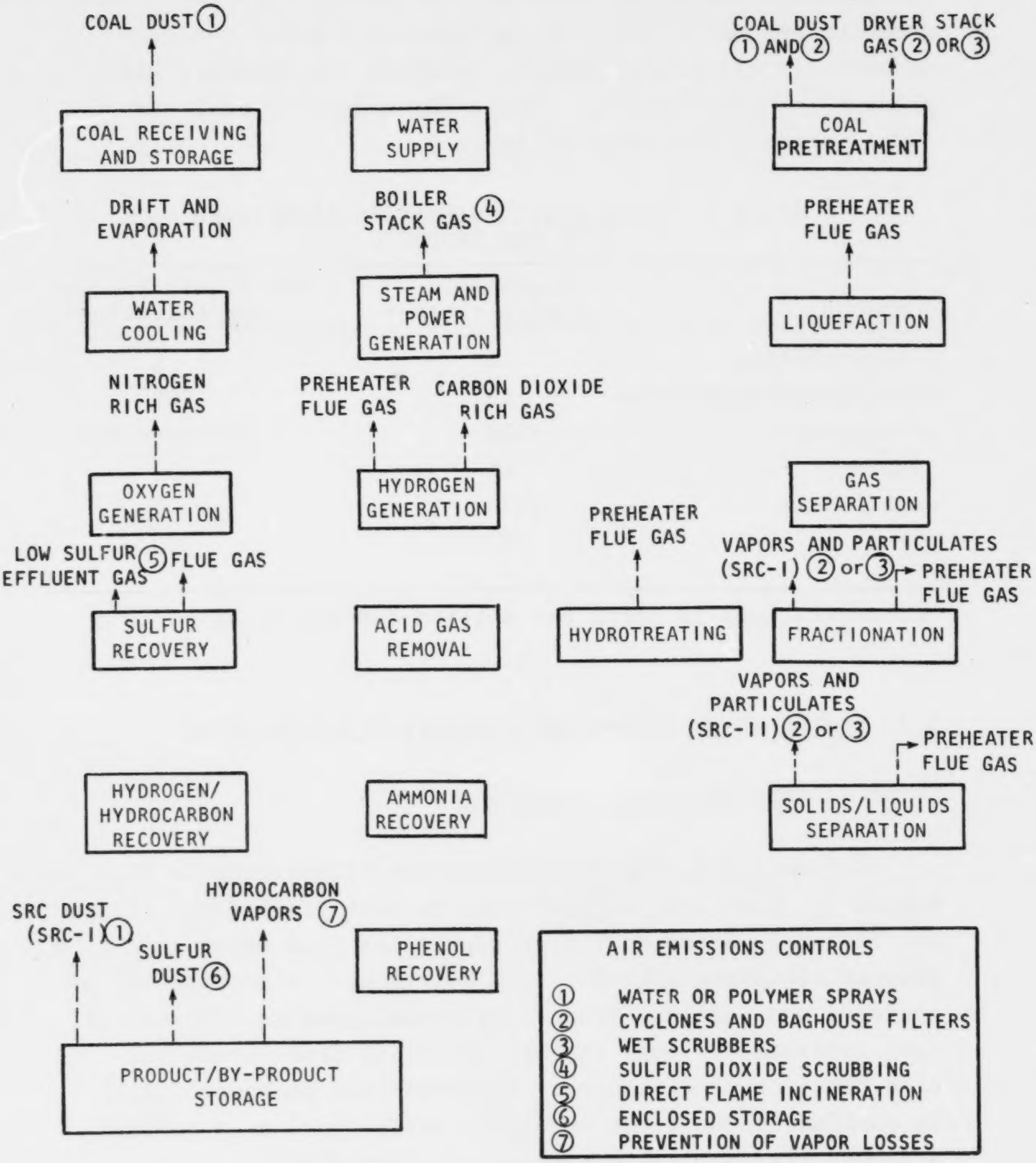

COAL DUST ①
COAL RECEIVING AND STORAGE
WATER SUPPLY
COAL DUST ① AND ②
DRYER STACK GAS ② OR ③
COAL PRETREATMENT
DRIFT AND EVAPORATION
WATER COOLING
BOILER STACK GAS ④
STEAM AND POWER GENERATION
PREHEATER FLUE GAS
LIQUEFACTION
NITROGEN RICH GAS
OXYGEN GENERATION
PREHEATER FLUE GAS
CARBON DIOXIDE RICH GAS
HYDROGEN GENERATION
GAS SEPARATION
LOW SULFUR EFFLUENT GAS
⑤ FLUE GAS
SULFUR RECOVERY
ACID GAS REMOVAL
PREHEATER FLUE GAS
HYDROTREATING
VAPORS AND PARTICULATES (SRC-I) ② or ③
PREHEATER FLUE GAS
FRACTIONATION
VAPORS AND PARTICULATES (SRC-II) ② or ③
PREHEATER FLUE GAS
SOLIDS/LIQUIDS SEPARATION
HYDROGEN/ HYDROCARBON RECOVERY
AMMONIA RECOVERY
SRC DUST (SRC-I) ①
SULFUR DUST ⑥
HYDROCARBON VAPORS ⑦
PHENOL RECOVERY
PRODUCT/BY-PRODUCT STORAGE
AIR EMISSIONS CONTROLS
① WATER OR POLYMER SPRAYS
② CYCLONES AND BAGHOUSE FILTERS
③ WET SCRUBBERS
④ SULFUR DIOXIDE SCRUBBING
⑤ DIRECT FLAME INCINERATION
⑥ ENCLOSED STORAGE
⑦ PREVENTION OF VAPOR LOSSES

Figure 7. Controls for air emissions from SRC systems

Vapors and particulates are produced during the solidification of residue in SRC-II systems and of SRC solid product when operating in the SRC-I mode. Either wet scrubbers or a combination of cyclones and baghouse filters can control the particulate emissions.

Boiler stack gas contains particulates and sulfur oxides. Sulfur dioxide scrubbers are effective in reducing discharge levels of particulates and sulfur oxides.

The effluent gas from sulfur recovery may be in compliance with applicable regulatory standards after direct-flame incineration. However, more stringently regulated plant sites may require additional treatment by a secondary sulfur recovery processes such as SCOT or Beavon, or by carbon adsorption treatment prior to incineration.

Air emissions are also associated with the product/by-product storage area. By-product sulfur dust may be controlled by enclosed storage of the sulfur. Solid SRC dust may be minimized by methods applicable to the feed coal storage pile. Hydrocarbon vapors from liquid products are best controlled through proper storage procedures, and preventive maintenance to minimize accidental vapor releases.

Many of the processes in SRC systems generate preheater flue gases. It is assumed that product substitute natural gas (SNG) shall be fired in these units, thereby permitting direct discharge to the atmosphere. In addition pressure relief valves periodically discharge gases rich in hydrocarbons from several of the processes. These releases are directed to the header of the flare system.

1.3.2 Water Effluents Control

Water effluent control options are shown in Figure 8. Wastewaters from coal cleaning are sent to a thickener. Overflow from the thickener is recycled to coal pretreatment High-solids underflow from the thickener, along with runoff waters from coal storage areas are routed to a tailings pond to permit settling of solids.

Blowdown from water cooling requires sidestream treatment prior to discharge to receiving waters. Ion exchange, electrodialysis and reverse osmosis are three processes commonly employed for this purpose.

Other process wastewaters from SRC systems are directed to the main wastewater treatment facility. Due to the similarity of wastewater from SRC with that from petroleum refineries, a similar approach to wastewater treatment is warranted. Process wastewater from ammonia recovery is steam stripped to remove hydrogen sulfide and any additional ammonia. The wastewater from phenol recovery is combined with the stripper effluent and directed to an API separator to reduce the amount of oil and grease in the water. Sour water from hydrogen production and acid gas removal are combined with the API separator outflow in an equalization basin. Dissolved air flotation is then employed, reducing levels of suspended solids and hydrocarbons in the combined wastewater. The effluent water from the equalization may then be sequentially treated by either of the alternatives shown below, each of which is commonly used in the petroleum industry.

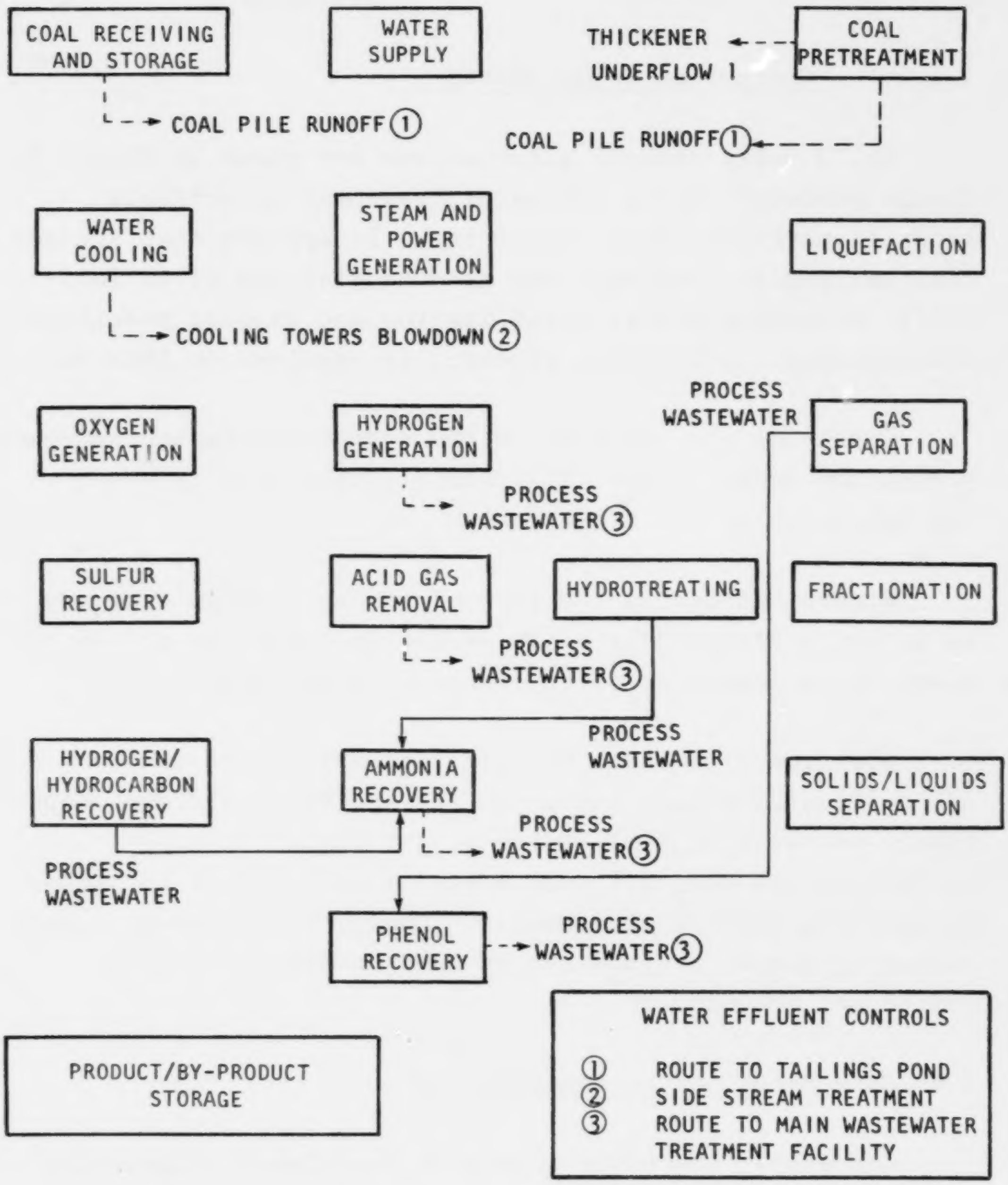

COAL RECEIVING AND STORAGE
WATER SUPPLY
THICKENER UNDERFLOW 1
COAL PRETREATMENT
COAL PILE RUNOFF ①
COAL PILE RUNOFF ①
WATER COOLING
STEAM AND POWER GENERATION
LIQUEFACTION
COOLING TOWERS BLOWDOWN ②
OXYGEN GENERATION
HYDROGEN GENERATION
PROCESS WASTEWATER
GAS SEPARATION
PROCESS WASTEWATER ③
SULFUR RECOVERY
ACID GAS REMOVAL
HYDROTREATING
FRACTIONATION
PROCESS WASTEWATER ③
PROCESS WASTEWATER
HYDROGEN/ HYDROCARBON RECOVERY
AMMONIA RECOVERY
SOLIDS/LIQUIDS SEPARATION
PROCESS WASTEWATER ③
PROCESS WASTEWATER
PHENOL RECOVERY
PROCESS WASTEWATER ③
PRODUCT/BY-PRODUCT STORAGE
WATER EFFLUENT CONTROLS
① ROUTE TO TAILINGS POND
② SIDE STREAM TREATMENT
③ ROUTE TO MAIN WASTEWATER TREATMENT FACILITY

Figure 8. Control of water effluents in SRC systems

Alternative I	Alternative II
Biological treatment by extended aeration	Biological treatment by aerated lagoon
Filtration	Settling basin
Discharge	Discharge

1.3.4 Control of Solid Wastes

Solid waste control alternatives are shown in Figure 9. Sludge produced during raw water treatment is suitable landfill material after dewatering. It appears that sludges from wastewater treatment may also be disposed of in landfills, providing proper stabilization and dispoal practices are employed. Additional research is required in this area.

Catalysts are employed in the hydrotreating and hydrogen production areas. Such catalysts are typically returned to the manufacturer for regeneration.

Mineral matter in the form of refuse, ash or slag may be directly disposed as solid wastes in landfills or, if the plant is in proximity of an abandoned mine, minefilling.

The mineral residue or filter cake produced during solids/liquids separation in SRC-II and SRC-I systems respectively contains high molecular weight organic species. It is recommended that all such material be gasified to render it safe for land or mine burial. Energy recovered by gasification of excess residue can be used on-site or sold as additional SNG product.

1.4 Data Needs and Recommendations

Currently, the pilot plants at Fort Lewis (Figure 10) and Wilsonville are the most advanced SRC facilities in

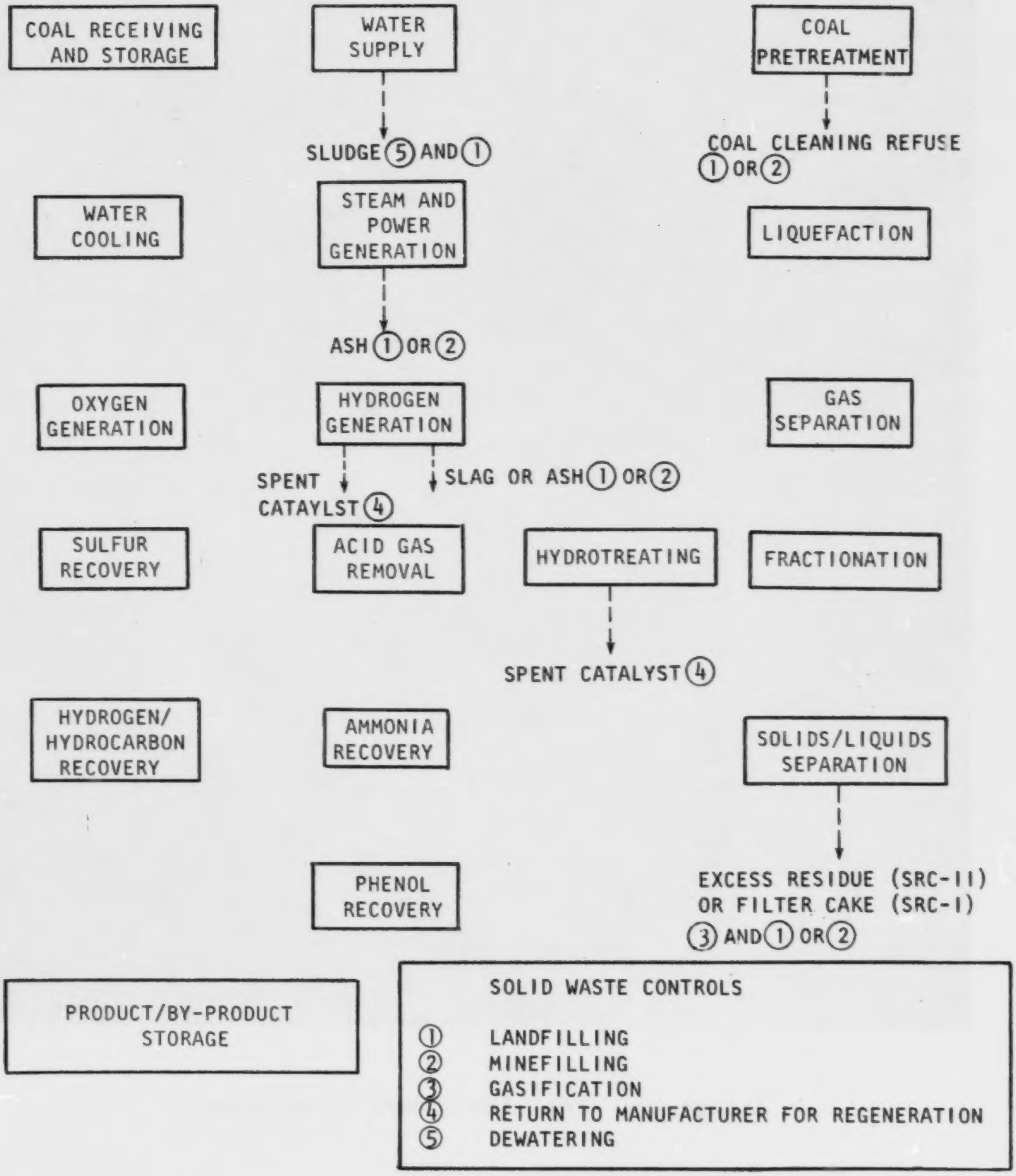

COAL RECEIVING AND STORAGE
WATER SUPPLY
COAL PRETREATMENT
SLUDGE ⑤ AND ①
COAL CLEANING REFUSE ① OR ②
WATER COOLING
STEAM AND POWER GENERATION
LIQUEFACTION
ASH ① OR ②
OXYGEN GENERATION
HYDROGEN GENERATION
GAS SEPARATION
SPENT CATAYLST ④
SLAG OR ASH ① OR ②
SULFUR RECOVERY
ACID GAS REMOVAL
HYDROTREATING
FRACTIONATION
SPENT CATALYST ④
HYDROGEN/ HYDROCARBON RECOVERY
AMMONIA RECOVERY
SOLIDS/LIQUIDS SEPARATION
PHENOL RECOVERY
EXCESS RESIDUE (SRC-II) OR FILTER CAKE (SRC-I) ③ AND ① OR ②
PRODUCT/BY-PRODUCT STORAGE
SOLID WASTE CONTROLS
① LANDFILLING
② MINEFILLING
③ GASIFICATION
④ RETURN TO MANUFACTURER FOR REGENERATION
⑤ DEWATERING

Figure 9. Control of solid wastes in SRC systems

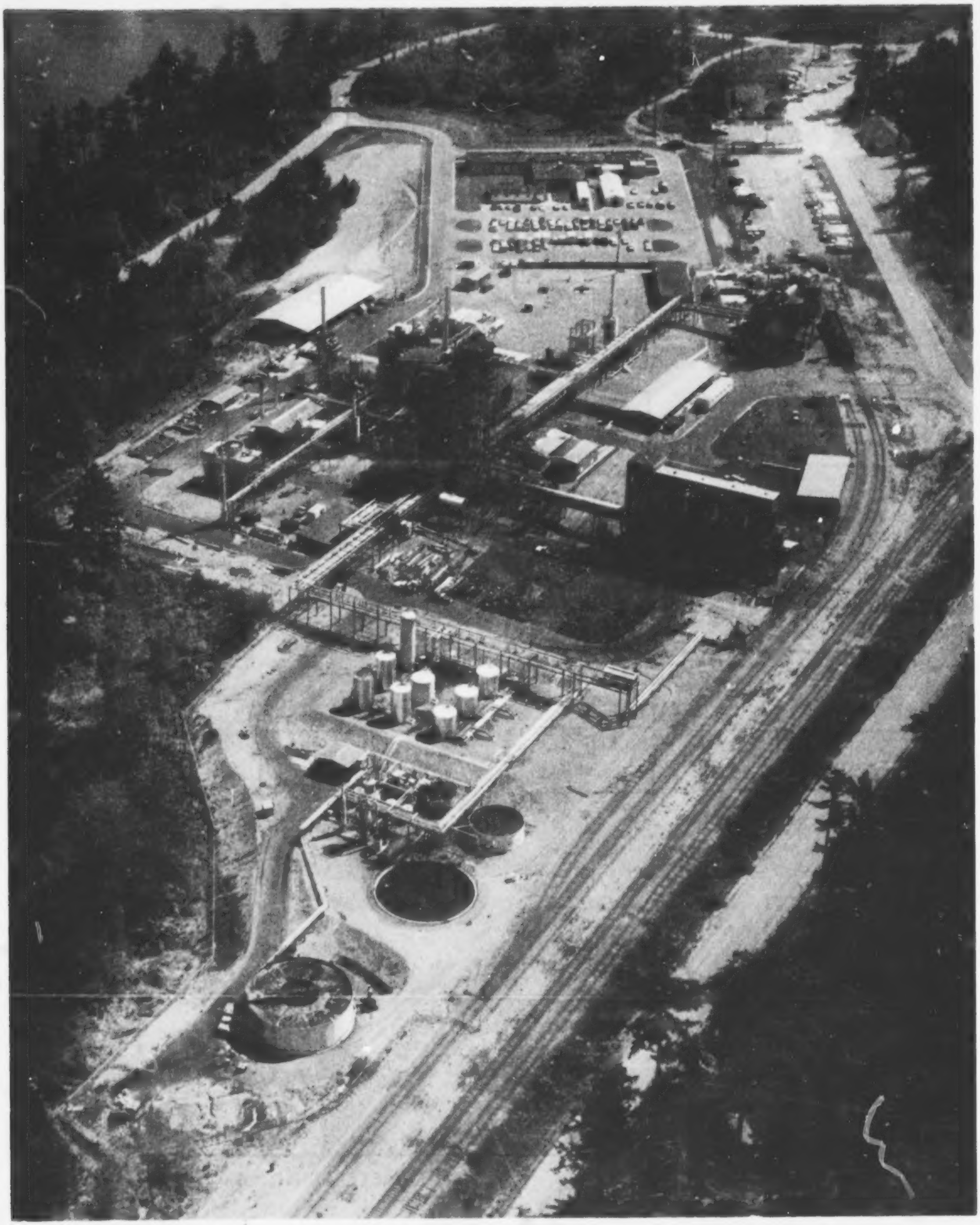


Figure 10. Fort Lewis SRC pilot plant

existence. Information obtained during solvent refining operations at Fort Lewis and Wilsonville is being used to design SRC demonstration plants. In an analogous manner, data from demonstration plants will be used to permit successful commercialization of SRC systems.

This environmental assessment is based on the best existing information, namely SRC pilot data, bench-scale data, and conceptual design studies. Just as additional operating data are required to permit commercialization of SRC systems, additional environmental assessment data are necessary to adequately characterize discharges, estimate environmental impacts, and evaluate control technology applicability relevant to SRC systems. Expansion of the existing environmental assessment data base for SRC systems should include the following areas:

- SRC stream characterization - with the purpose of developing representative physical, chemical (inorganic and organic) and biological (with bioassays) characteristics of SRC plant streams, in particular before and after treatment waste streams. While characterization of waste streams is most essential to environmental assessment, better characterized process streams will permit construction of an advanced material balance, ideally permitting one to "track" pollutants through the SRC system to the environment.

- Determination of the variability of waste stream characteristics due to changes in system operating characteristics - an expanded data base on stream characteristics may permit such correlations, possibly suggesting ideal operating conditions for minimized environmental effects.

- Performance evaluations and costs of applicable control technology alternatives

- Reassessments of environmental impacts based on the expanded data base.

Due to the relative applicability of SRC pilot plant data, the above efforts would be more beneficial if performed at SRC demonstration facilities.

Environmental assessment methodologies such as Multimedia Environmental Goals (MEGs), and Source Analysis Models (SAMs) have been developed to provide an organized, consistent approach for evaluation of emerging energy technologies such as SRC. Technically, there are many differences between existing SRC pilot facilities and the demonstration and commercial plants of the future. Consequently operating data or process and waste stream characteristics from the pilot plant are only an indication of commercial or demonstration plant behavior.

However, sampling, analysis and application of environmental assessment methodologies to pilot plant data are essential to permit the following prior to emergence of SRC systems into the commercial sector:

- Sampling and analysis techniques may be tried and any problem areas identified, thereby permitting refinement of the techniques

- Sampling and analysis priorities for the demonstration/pilot SRC facilities may be identified based on pilot studies

- Application of the environmental assessment methodologies to SRC pilot data will allow additional development and evaluation

- Each of the above activities will provide those involved with SRC systems with the necessary expertise to confidently assess commercial SRC systems at the time technical progress and economic conditions permit their emergence.

The following recommendations can be made regarding future environmental assessments of SRC systems:

- Efforts to characterize waste streams, process streams, products and by-products should be continued at an increased level of effort. In so doing, numerous benefits are derived including expansion of the preliminary data base on SRC systems, optimization of sampling and analysis procedures, and additional sophistication of environmental impact methodologies. Results of these efforts will be invaluable in establishing priortized research needs for environmental characterization of SRC demonstration/commercial facilities.

- Efforts should be undertaken to define suitable sites for commercial SRC facilities. Subsequent to definition, applicable sites should be identified. Information required to perform site-specific environmental impact analyses should be collected for those sites identified as potentially suitable for SRC facilities including pre-construction ambient air and water quality monitoring.

Initiation of expanded background monitoring studies in applicable locations would be useful for environmental assessment and could hasten construction of commercial facilities.

- Candidate control technologies identified as applicable to control of wastes from SRC systems should be tested at SRC pilot and demonstration facilities to the extent technically and economically feasible. Sampling and analysis of discharge streams before and after treatment would greatly expand the environmental assessment data base. Small-scale, skid mounted control technology units could be placed on flatbed trucks and moved to pilot or demonstration facilities for testing with continuous samples of the plant's waste stream, thereby providing a cost-effective means of performance testing numerous candidate control options.

- Continued efforts should be made to promote cooperation, coordination and information exchange between the various private and government organizations involved in development and environmental analysis of SRC systems. Preparation and presentation of technical papers at appropriate symposia and other technical meetings is an excellent way to informally stimulate interaction of researchers, leading to more formal interaction during performance of research.

- As SRC systems enter the demonstration stage and available information applicable to environmental assessment increases, consideration should be given to preparing separate Environmental Assessment Reports on the SRC-I and SRC-II systems.

The benefits include reduced redundance of environmental assessment efforts, permitting optimum utilization of available research funds.

2.0 PROCESS DESCRIPTION OF SOLVENT REFINED COAL SYSTEMS

2.1 Technical Overview of Solvent Refined Coal Systems

2.1.1 Status of Development

2.1.1.1 Origin and History of Solvent Refined Coal Systems

Solvent Refined Coal (SRC) Systems convert high sulfur and ash coal into clean-burning gaseous, liquid and/or solid fuels by noncatalytic direct hydrogenation. There are two basic system variations: (1) SRC-I, which produces a solid, coal-like primary product of less than 1.0 percent sulfur and 0.2 percent ash by weight; and (2) SRC-II, which produces low sulfur fuel oil (0.2-0.5 percent sulfur by weight) and naphtha as primary products.

In 1962 the Spencer Chemical Company was awarded a contract by the Office of Coal Research (OCR) to investigate the technical feasibility of a coal deashing process (1). The contract was successfully completed by demonstrating process feasibility in a 22.7 kg/hr continuous flow unit. This process of coal deashing was named the Solvent Refined Coal (SRC) process. Further development of the deashing process has led to the development of the SRC liquefaction systems addressed in this report.

In the course of completing the initial contract Spencer Chemical Company was acquired by Gulf Oil Corporation. Subsequent to acquisition of Spencer Chemical Company, the contract was reassigned to the research department of the Pittsburg and Midway Coal Mining Company (P&M), also part of Gulf Oil Corporation (1).

Further development of solvent refining was facilitated by an OCR contract awarded to P&M to design, construct and operate a pilot plant with a coal throughput capacity of 45.5 Mg/day. Stearns-Roger Corporation completed the design phase in 1969. In 1972, OCR extended the contract with P&M, authorizing construction and operation of the pilot plant. Construction of the pilot facility, located at Fort Lewis, Washington, was performed by the Rust Engineering Company between 1972 and 1974, when the plant became fully operational (1).

A number of significant accomplishments have resulted from operation of the Fort Lewis pilot plant (1). Major pilot plant efforts have included:

- Tests to determine the effects of varied coal feed rates and dissolver (liquefaction reactor) temperatures on SRC system operations.

- Production of approximately 2700 Mg of SRC for combustion testing by Southern Company Services' Georgia Power Company at Plant Mitchell, near Albany, Georgia in May and June of 1977.

- Testing of various filtration alternatives for solids/liquids separation.

- Studies of the SRC-II (slurry recycle) modification of the system.

- Combustion testing of approximately 800 m^3 of SRC-II liquid product produced at Fort Lewis while operating in the SRC-II mode. The tests conducted at Consolidated Edison in New York in September of 1978, assessed the storage, handling, combustion and emissions characteristics of SRC-II liquid fuel (5).

- Successful resolution of many mechanical problems identified during pilot plant startup and early operation.

In a separate effort, Edison Electric Institute and Southern Company Services, Inc., with funding from OCR, began a joint study of SRC liquefaction (1). A contract was awarded to Catalytic, Inc. to design, build and operate a 5.5 Mg/day SRC pilot plant located in Wilsonville, Alabama. The Electric Power Research Institute assumed utility industry sponsorship in 1973.

In addition to the SRC pilot plant work, supporting research has been performed (1) including:

- Bench-scale laboratory studies at P&M in Merriam, Kansas.

- Catalyst development for desulfurization and denitrogenation of coal liquids, performed at Oklahoma State University.

- Analysis of coal mineral residues and the fate of trace elements in SRC systems by Washington State University.

2.1.1.2 Current Status

The current (as of March 1978) schedule for development of SRC is shown in Figure 11 (2). Current efforts at Fort Lewis are aimed at improving existing filtration and solvent deashing techniques, environmental monitoring programs, and toxicity studies of liquids and solids produced by the plant (2). Under the existing contract, pilot plant operation and evaluation of the SRC-II process are authorized through 1981. Laboratory studies at P&M in Merriam, Kansas are scheduled for completion at the end of 1978.

Evaluation of the SRC process development unit (PDU) in Wilsonville, Alabama began early in 1973. Under the existing contract, the PDU will continue to operate until the end of 1979. Planned work efforts in this area are improvement of solid SRC production, and testing of alternatives for solids/liquids separation (2).

2.1.1.3 Announced Future Plans

Contracts have recently been awarded to P&M and Southern Company Services by DOE to design demonstration plants employing SRC liquefaction technology (3,4). Each plant will have a design capacity of about 5500 Mg/day.

The P&M design is to be based on SRC-II technology, for a plant that would be located near Morgantown, West Virginia. The Southern Company Services design will be based on the SRC-I operating mode, for a location near Owensburg, Kentucky (4). Pending DOE evaluation, follow up work could include implementation of the designs through construction and operation of the demonstration facilities. Should construc-

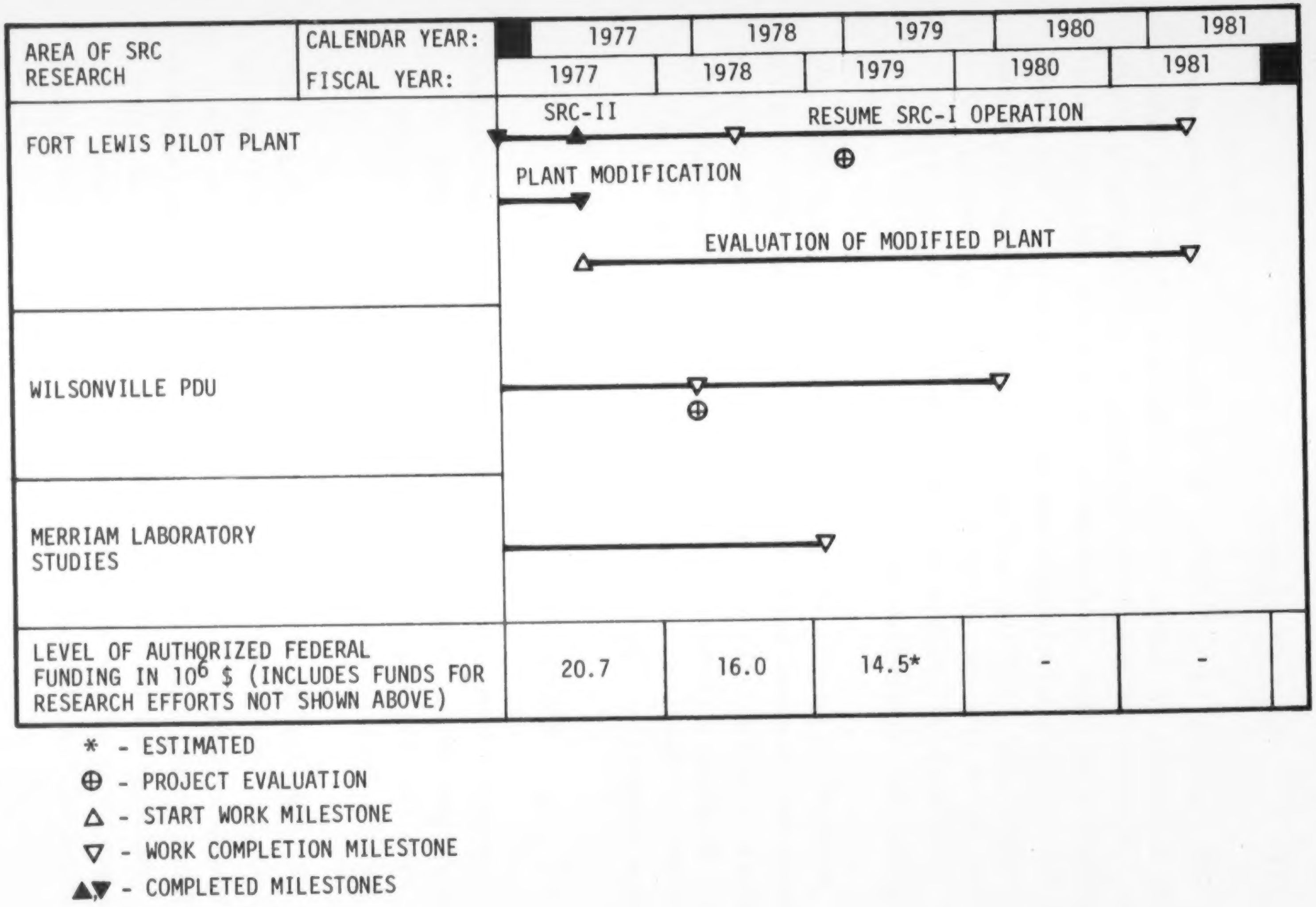


Figure 11. Current schedule for SRC research and development

tion of the demonstration plants be approved, the plants could begin operation as early as 1983 (4). In addition, if the demonstration plants operate successfully, parallel trains could be added to increase plant capacity to commercial levels producing the equivalent of around 16,000 m^3/day of fuel (4).

Recently, West Germany and Japan have expressed interest in making development of SRC-II an interntional venture. Although negotiations are far from complete, the West German and Japanese governments are willing to assist in funding SRC-II projects in exchange for access to technical data collected (5).

2.1.2 Industrial Applicability of SRC Systems

The primary product from coal liquefaction by the SRC-I mode is a low-ash, low sulfur coal liquid which solidifies between 175° and 205°C (2). The primary application of solid SRC is as a boiler fuel, for power generation in the utility industry, and for production of steam, heat and power in other heavy industries such as iron and steel manufacturing.

The more versatile liquid product resulting from operation in the SRC-II mode is also a suitable feedstock for industrial boilers. Application of petroleum refinery technology could permit upgrading of liquid SRC to distillate fuels such as light and medium oils, diesel fuel, naphthas, kerosene, and gasoline. Alternatively, the SRC-II product liquid could serve the petrochemical industry as a feedstock from which a wide variety of organic chemicals could be produced.

No legislation currently exists directly pertinent to SRC liquefaction systems (6). However, the EPA New Source Performance Standards for those existing industries and industrial operations which are technologically similar to component parts of SRC systems may provide some insight as to the standards which will be promulgated to govern SRC systems discharges. The EPA industrial source categories most applicable to SRC systems and product utilization include petroleum refining, iron and steel manufacturing, steam electric power plants, water supply, steam supply, and the coal preparation segment of the coal mining industry. The aspects of environmental regulation of SRC systems are discussed in detail in Section 5.0.

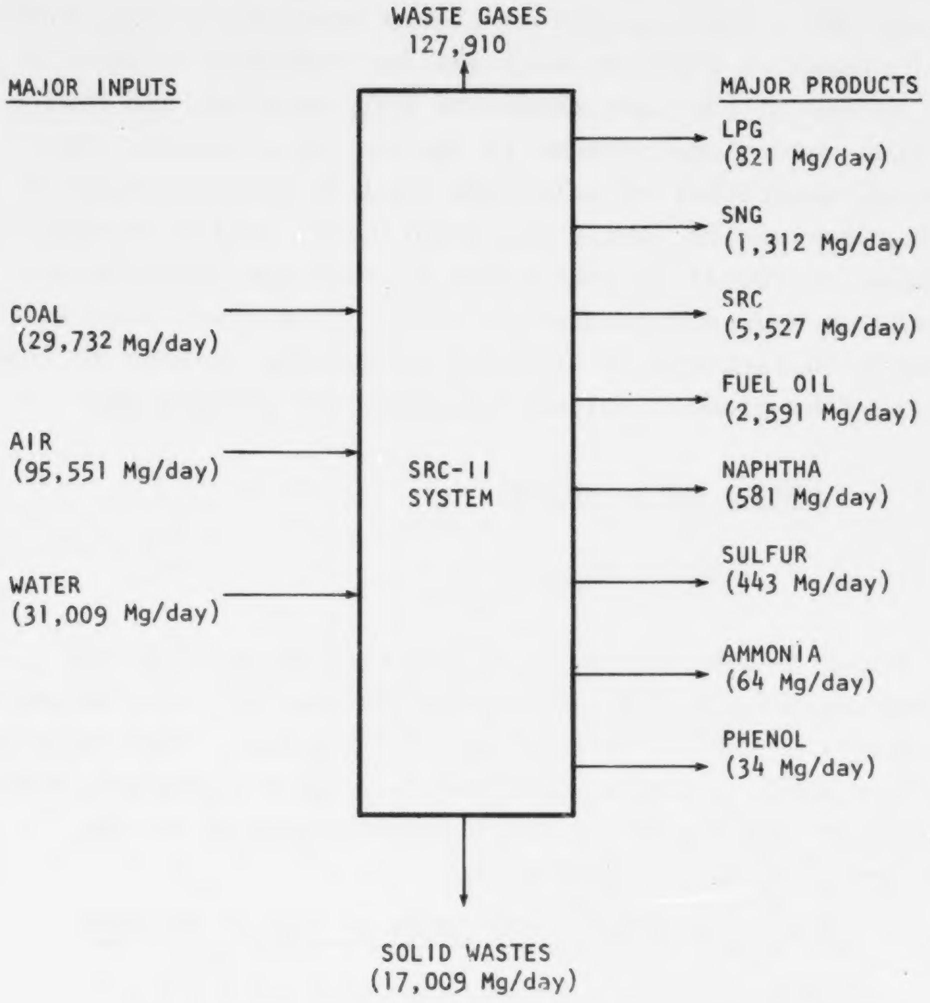
2.1.3 Input Materials, Products and By-Products

2.1.3.1 SRC-II Mode

An overall material balance, showing major system inputs, products and by-products is shown in Figure 12 (6). The primary liquid products are liquid SRC and fuel oil, although a naphtha fraction also is produced. Gaseous hydrocarbons formed during the reaction of the coal are processed to produce liquefied petroleum gas (LPG) and substitute natural gas (SNG). Some constituents produced by coal hydrogenation are recovered as saleable by-products, including sulfur, ammonia, and phenol (6).

2.1.3.2 SRC-I Mode

Operation in the SRC-I mode results in a mix of products and by-products significantly different than what is shown in Figure 12 for SRC-II. For example, lower quantities of hydrocarbon gases are produced (7,8). The LPG and SNG pro-


WASTE GASES
127,910
MAJOR INPUTS
MAJOR PRODUCTS
COAL
(29,732 Mg/day)
AIR
(95,551 Mg/day)
WATER
(31,009 Mg/day)
SRC-II
SYSTEM
LPG
(821 Mg/day)
SNG
(1,312 Mg/day)
SRC
(5,527 Mg/day)
FUEL OIL
(2,591 Mg/day)
NAPHTHA
(581 Mg/day)
SULFUR
(443 Mg/day)
AMMONIA
(64 Mg/day)
PHENOL
(34 Mg/day)
SOLID WASTES
(17,009 Mg/day)

NOTE: All flowrates in Mg/day.

Figure 12. Overall material balance for SRC-II systems with product capacity of 7,950 m^3/day (8,699 Mg/day)

duced by SRC-I are consumed in meeting system heating requirements whereas SRC-II provides a surplus of marketable LPG and SNG. The quantity of liquid products exiting the SRC-I system is substantially smaller compared to SRC-II. This is due to the less extensive hydrogenation and hydrocracking conditions present in SRC-I. As a result, substantial quantities of solid SRC product are generated by SRC-I liquefaction, while the quantity of solids residue produced in SRC-II is controlled to meet the capacity required for hydrogen production (7,8). The lower reaction severity characteristic of SRC-I processing results in lower yields of by-product sulfur, ammonia, and phenols (6).

2.1.4 Energy Efficiencies

2.1.4.1 SRC-II Mode

Based on the Standards of Practice Manual for the Solvent Refined Coal Liquefaction Process (6), the thermal efficiency of SRC-II systems is 71.8 percent. Heat balance data are shown in Table 6. This is in good agreement with the energy efficiency of 70.3 percent reported by the developers of SRC systems (7,8).

TABLE 6. ENERGY EFFICIENCY OF SRC-II SYSTEMS

Inputs	J/kg
Coal	1.37
Electrical power	0.05
Total	1.42
Outputs	
SNG	0.20
LPG	0.09
Naphtha	0.05
Fuel oil	0.23
Liquid SRC	1.02
Total	1.02

Thermal efficiency = 71.8 percent

2.1.4.2 SRC-I Mode

Exxon Research and Engineering (9) has reported a thermal efficiency of 63.0 percent for SRC-I systems. It is also noted that with improvements such as reducing hydrogen consumption, the thermal efficiency could be improved to greater than 70 percent (9). Developers of SRC systems have reported the thermal efficiencies of conceptual SRC-I and SRC-II systems to be 70.3 and 71.0 percent respectively (8).

2.1.5 Capital and Operating Costs

Numerous research efforts (8,10,11,12,13,14,15) have investigated the economic aspects of SRC systems. One of the more recent efforts compares the SRC-I and SRC-II systems in terms of capital and operating costs. In addition, minimum selling prices for SRC products are determined for each operating mode for selected economic scenarios.

Table 7 shows the capital cost estimates for SRC-I and SRC-II plants based on conceptual design information for an assumed feed capacity of about 27,300 Mg of coal per day. This corresponds to roughly 95 percent of the capacity of the hypothetical facility described; costs shown in Table 7 would be similar for the hypothetical facilities. While overall capital costs for the two alternatives are about the same there are important differences in costs for corresponding plant areas. Filtration, used for solids/liquids separation in SRC-I is not required in the slurry recycle SRC-II mode. In addition, the quantity of solid carbonaceous residue produced by the SRC-II mode can be controlled. By designing so that just enough residue is generated to provide solidification can be obviated for the SRC-II mode. Due to the increased degree of hydrogenation associated with the

TABLE 7. SUMMARY OF CAPITAL COSTS FOR CONCEPTUAL SRC PLANTS*

Plant Area	Cost, $ x 10^6	
	SRC-I	SRC-II
Coal pretreatment	81	81
Hydrogenation**	198	367
Fractionation	24	22
Hydrogen plant	307	277
Filtration	172	NR
Product solidification	25	NR
Hydrocarbon/by-product recovery	81	117
Utilities/off-sites	99	114
General facilities	77	76
Total Cost	1064	1054

* Basis: November 1976 dollars, based on conceptual plant processing of approximately 27,300 Mg coal/day

**Includes cost of hydrogen recycle

NR - Not required for liquefaction by SRC-II.

SRC-II mode the capital costs associated with hydrogenation, hydrocarbon gas and by-product recovery is also higher than for the same areas of an SRC-I facility. The process developers (8) state that higher cost for the hydrogen plant in the SRC-I case is due to the fact that an ambient pressure gasifier will be employed because of SRC-I system characteristics. A less costly pressurized gasifier is specified for the SRC-II system (8). Annual operating costs of SRC-I and SRC-II systems, based on November 1976 dollars, are estimated to be 118 and 83 million dollars respectively. Other capital costs, such as land, working capital, licensing costs and startup expenses are estimated to be 88 million dollars for SRC-I and 79 million dollars for SRC-II, based on November 1976 dollars.

Table 8 summarizes the selling prices required, on a cost per energy unit basis, for investment return assuming escalation rates of zero and six percent, contingencies of 10 to 20 percent, and discounted cash flow (DCF) rates of 12 and 15 percent for SRC-I and SRC-II plants (8). The lowest selling price, $2.63/GJ of SRC-II product (assuming six percent escalation, 10 percent contingency and 15 percent DCF) is still above the estimated current sales price of No. 6 fuel oil (1% sulfur), $2.09/GJ (16,17). Although the economics do not appear to favor market penetration by synthetic fuels, either changes in oil-exporting nation's pricing policies or federal government subsidies for synthetic fuel producers or consumers could hasten commercialization.

TABLE 8. REQUIRED SELLING PRICE FOR INVESTMENT RETURN - SRC-I AND SRC-II MODES

Constant Dollars (assumes 0% escalation)	SRC-I		SRC-II	
Contingency:	10%	20%	10%	20%
Selling price* (assumes 12% DCF):	3.34	3.49	3.24	3.39
Selling price (assumes 15% DCF):	3.84	3.99	3.74	3.89
Current** dollars (assumes 6% escalation)	SRC-I		SRC-II	
Contingency:	10%	20%	10%	20%
Selling price (assumes 12% DCF):	2.63	2.70	2.51	2.58
Selling price (assumes 15% DCF):	2.95	3.03	2.83	2.91

---

* All selling prices in $/GJ

**Based on November 1976 dollars.

2.1.6 Commercial Prospects

2.1.6.1 SRC-I Mode

Current government policy advocates increased domestic utilization of coal. Combustion of high-sulfur coal requires stack gas scrubbing to meet emissions standards. Solvent refining reduces the sulfur content of feed coals, permitting combustion while eliminating the need for stack gas scrubbing. The SRC-I combustion test indicates that SRC-I solid fuel is a potentially acceptable boiler fuel which complies with existing EPA emissions standards (18). Endorsement of SRC-I as a boiler fuel by Southern Company Services, Inc. indicates the evident utility demand and potential market penetration of SRC-I fuel.

Successful completion of the SRC-I demonstration program discussed earlier will help to determine the technical and economic viability of commercial SRC-I facilities. Commercial prospects of the SRC-I system will be greatly enhanced if the filtration and product solidification areas can be operated efficiently at the demonstration level. Operation of the demonstration facility will also permit better definition of the cost of commercially producing solid fuel with the SRC-I system.

2.1.6.1 SRC-II Mode

Commercial prospects for the SRC-II system appear to be more cost dependent than the SRC-I. The problems associated with filtration and product solidification in the SRC-I mode do not exist since they are not part of the SRC-II processing scheme. The SRC-II demonstration program will further refine commercial production cost estimates. Once

SRC-II liquids can be sold at prices competitive with natural petroleum products, market penetration could begin in any of the numerous applicable areas where SRC-II liquid products can be substituted for natural petroleum products.

2.2 Description of Processes

This subsection discusses those processes which comprise the SRC-I and SRC-II systems. Discussions are based on the generalized flow diagrams shown in subsection 2.2.1; however, it should be noted that no fixed flow chart exists for either SRC-I or SRC-II commercial facilities at this time. Possible variations are identified in the individual process discussions. Process discussions emphasize the SRC-II mode because of information developed during a previous work effort (6); however, significant differences between the SRC-I and SRC-II modes are identified and discussed where appropriate.

2.2.1 Generalized System Flow Diagrams

To facilitate an understanding of the basic components of the SRC systems, a modular approach is taken. In the modular approach, the SRC systems are subdivided into operations. Each operation is accomplished by carrying out a group of processes, a process being the smallest unit of the overall system. Auxiliary processes perform functions incidental to the functions of system operations. All processes may be represented visually by process modules which display process input and output stream characteristics. Sets of process modules may be used to describe SRC system operation, the overall SRC-I and SRC-II systems, or the entire coal liquefaction energy technology. Control equipment facilities and final disposal processes are discussed in Section 4.0. The SRC-I and SRC-II systems are described using the modular approach in the following subsections.

2.2.1.1 SRC-II Mode

Figure 13 is a generalized flow diagram of the operations, auxiliary processes, control equipment facilities and final disposal processes comprising SRC-II systems. Coal from storage is sized, dried, and mixed with recycled product slurry recovered from the gas separation process. The mixture of coal and recycled slurry is pumped, along with hydrogen from the hydrogen production and hydrocarbon recovery processes, through a preheater to a liquefaction reactor, commonly referred to as a dissolver. The ratio of slurry to coal in the feed mixture is typically 1.5 to 2.5. The hydrogen to coal ratio is about 1,250 scm/Mg (8).

The reaction mixture exits the preheater at a temperature of about 370°-400°C. The increase in temperature due to preheating initiates hydrogenation and hydrocracking reactions in the coal/slurry/hydrogen mixture. Heat produced by these reactions raises the temperature to about 435°-470°C in the liquefaction reactor.

The product slurry exiting the dissolver enters the gas separation process where gaseous species produced in the reactor are removed utilizing flash separators, heat exchangers, and condensers. Condensed oils recovered from the flashing process are sent to the fractionation process. The mixture of noncondensible gases is further processed, to remove gaseous sulfur species and recover the sulfur as a by-product, to recover unreacted hydrogen for recycle to the coal pretreatment operation and to recover gaseous hydro-

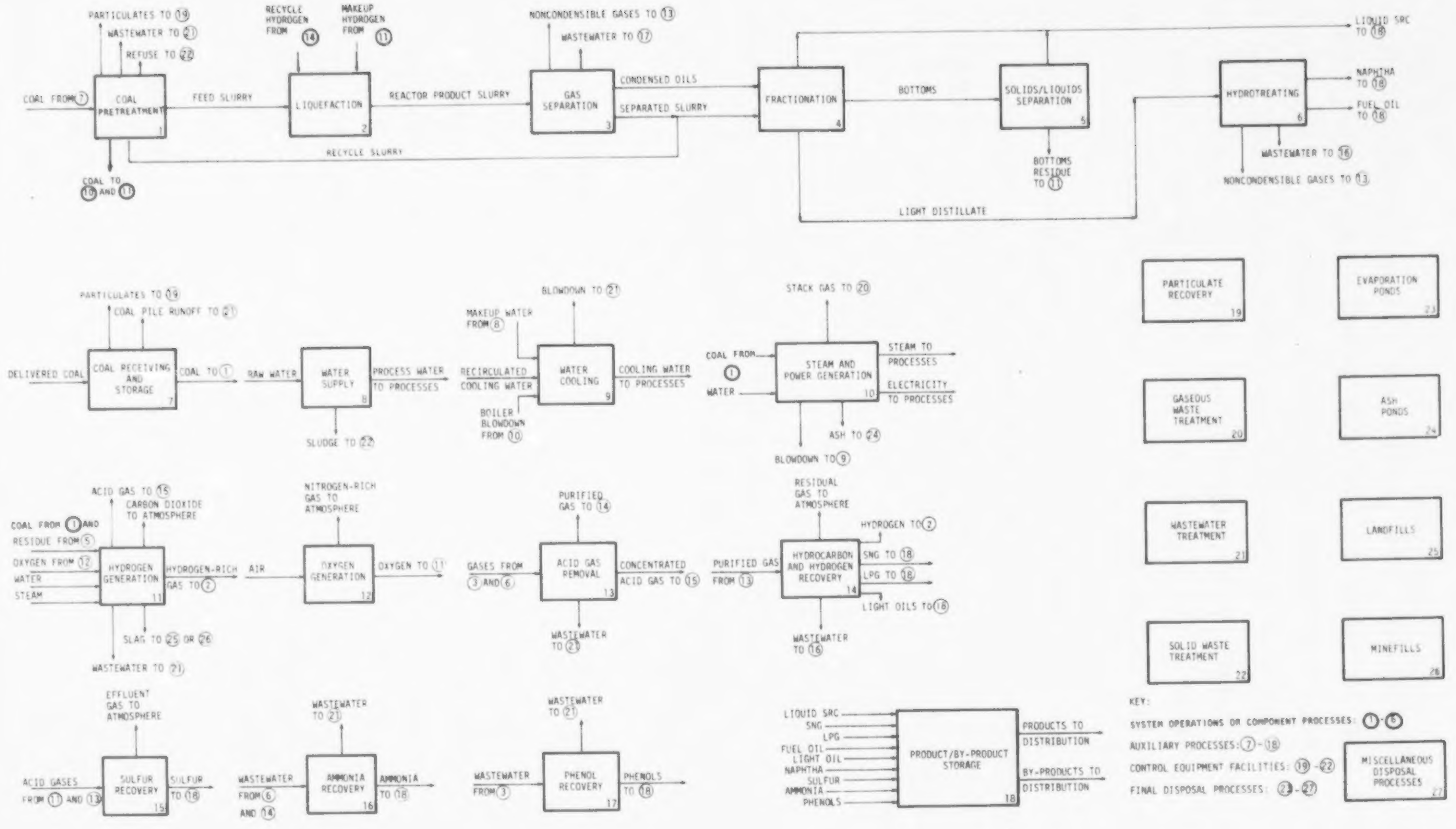

PARTICULATES TO ⑲
WASTEWATER TO ㉑
REFUSE TO ㉒
COAL FROM ⑦
COAL PRETREATMENT
1
COAL TO ⑩ AND ⑪
FEED SLURRY
RECYCLE HYDROGEN FROM ⑭
MAKEUP HYDROGEN FROM ⑪
LIQUEFACTION
2
REACTOR PRODUCT SLURRY
RECYCLE SLURRY
NONCONDENSIBLE GASES TO ⑬
WASTEWATER TO ⑰
GAS SEPARATION
3
CONDENSED OILS
SEPARATED SLURRY
FRACTIONATION
4
BOTTOMS
SOLIDS/LIQUIDS SEPARATION
5
BOTTOMS RESIDUE TO ⑪
LIGHT DISTILLATE
LIQUID SRC TO ⑱
HYDROTREATING
6
NAPHTHA TO ⑱
FUEL OIL TO ⑱
WASTEWATER TO ⑯
NONCONDENSIBLE GASES TO ⑬
PARTICULATES TO ⑲
COAL PILE RUNOFF TO ㉑
DELIVERED COAL
COAL RECEIVING AND STORAGE
7
COAL TO ①
RAW WATER
WATER SUPPLY
8
PROCESS WATER TO PROCESSES
SLUDGE TO ㉒
MAKEUP WATER FROM ⑧
BLOWDOWN TO ㉑
RECIRCULATED COOLING WATER
BOILER BLOWDOWN FROM ⑩
WATER COOLING
9
COOLING WATER TO PROCESSES
STACK GAS TO ⑳
COAL FROM ①
WATER
STEAM AND POWER GENERATION
10
STEAM TO PROCESSES
ELECTRICITY TO PROCESSES
ASH TO ㉔
BLOWDOWN TO ⑨
ACID GAS TO ⑮
CARBON DIOXIDE TO ATMOSPHERE
COAL FROM ① AND
RESIDUE FROM ⑤
OXYGEN FROM ⑫
WATER
STEAM
HYDROGEN GENERATION
11
HYDROGEN-RICH GAS TO ②
SLAG TO ㉕ OR ㉖
WASTEWATER TO ㉑
NITROGEN-RICH GAS TO ATMOSPHERE
AIR
OXYGEN GENERATION
12
OXYGEN TO ⑪
PURIFIED GAS TO ⑭
GASES FROM ③ AND ⑥
ACID GAS REMOVAL
13
CONCENTRATED ACID GAS TO ⑮
WASTEWATER TO ㉑
RESIDUAL GAS TO ATMOSPHERE
HYDROGEN TO ②
PURIFIED GAS FROM ⑬
HYDROCARBON AND HYDROGEN RECOVERY
14
SNG TO ⑱
LPG TO ⑱
LIGHT OILS TO ⑱
WASTEWATER TO ⑯
EFFLUENT GAS TO ATMOSPHERE
ACID GASES FROM ⑪ AND ⑬
SULFUR RECOVERY
15
SULFUR TO ⑱
WASTEWATER TO ㉑
WASTEWATER FROM ⑥ AND ⑭
AMMONIA RECOVERY
16
AMMONIA TO ⑱
WASTEWATER TO ㉑
WASTEWATER FROM ③
PHENOL RECOVERY
17
PHENOLS TO ⑱
LIQUID SRC
SNG
LPG
FUEL OIL
LIGHT OIL
NAPHTHA
SULFUR
AMMONIA
PHENOLS
PRODUCT/BY-PRODUCT STORAGE
18
PRODUCTS TO DISTRIBUTION
BY-PRODUCTS TO DISTRIBUTION
PARTICULATE RECOVERY
19
GASEOUS WASTE TREATMENT
20
WASTEWATER TREATMENT
21
SOLID WASTE TREATMENT
22
EVAPORATION PONDS
23
ASH PONDS
24
LANDFILLS
25
MINEFILLS
26
MISCELLANEOUS DISPOSAL PROCESSES
27
KEY:
SYSTEM OPERATIONS OR COMPONENT PROCESSES: ①-⑥
AUXILIARY PROCESSES: ⑦-⑱
CONTROL EQUIPMENT FACILITIES: ⑲-㉒
FINAL DISPOSAL PROCESSES: ㉓-㉗

Figure 13. Generalized flow diagram of SRC-II system.

carbons as both SNG and LPG. Part of the recovered hydrocarbon gases can be used to provide plant fuel requirements. The slurry exiting the flash separator passes to the fractionation process to separate the mixture of hydrocarbons and solids into the major products of the system. A portion of the slurry, however, is diverted from fractionation back to coal pretreatment for mixing with feed coal and hydrogen.

In the fractionation process, an atmospheric distillation unit separates the entering slurry into a naphtha stream, a middle distillate stream, and a bottoms stream. The naphtha and middle distillate may be stored as products or be further upgraded in the hydrotreating process. Although hydrotreating is not included in many recent SRC conceptual designs (8) it has been retained in this design (6) to permit environmental assessment of the wastes potentially exiting a commercial SRC facility which may elect to hydrotreat the products.

The bottoms stream from the atmospheric distillation unit is sent to a vacuum still in the solids/liquids separation process. Overhead from this unit is similar to the middle distillate exiting the atmospheric still. (This stream also may be optionally hydrotreated.) The bottoms from the vacuum distillation unit, consisting of undissolved mineral matter and high-boiling hydrocarbon residuals is fed to the hydrogen generation auxiliary process as a feedstock from which makeup hydrogen is produced.

In addition to the hydrogen generation process the following auxiliary processes are present in the SRC-II system: coal receiving and storage, water supply, water cooling, steam and power generation, oxygen generation, acid gas removal, hydrocarbon and hydrogen recovery, ammonia recovery, phenol recovery and product/by-product storage.

Detailed discussions of the operations and auxiliary processes which comprise the SRC-II system may be found in subsections 2.2.2 through 2.2.8.

2.2.1.2 SRC-I Mode

The SRC-I system is shown in Figure 14. The major differences between it and the SRC-II system lie in the location of the solids/liquids separation process and the separation method employed. Instead of vacuum distillation, filtration is used for solids/liquids separation. Filter cake produced by the filtration process, along with supplemental coal from the coal pretreatment operation is gasified to provide makeup hydrogen. The quantity of hydrocarbon gases recovered in SRC-I meets plant fuel demands, however, there is no marketable surplus of gas as in SRC-II operation. Solids/liquids separation will precede fractionation in SRC-I. The opposite is true in the SRC-II system. In the fractionation process, part of the feedstream is recycled to the coal pretreatment area as recycle solvent as opposed to the slurry mixture recycled in SRC-II. One fractionation output stream, the middle distillate, is recycled to the filtration process as a wash solvent. The other operations and auxiliary processes of the SRC-I system operate generally the same as in the SRC-II mode.

Subsections 2.2.2 through 2.2.8 discuss the system operations and auxiliary processes of the SRC-II system. Where applicable, significant differences in the SRC-I system are also noted.

2.2.2 Coal Pretreatment

Figure 15 is a schematic flow diagram showing the processes comprising the coal pretreatment operation. Coal re-

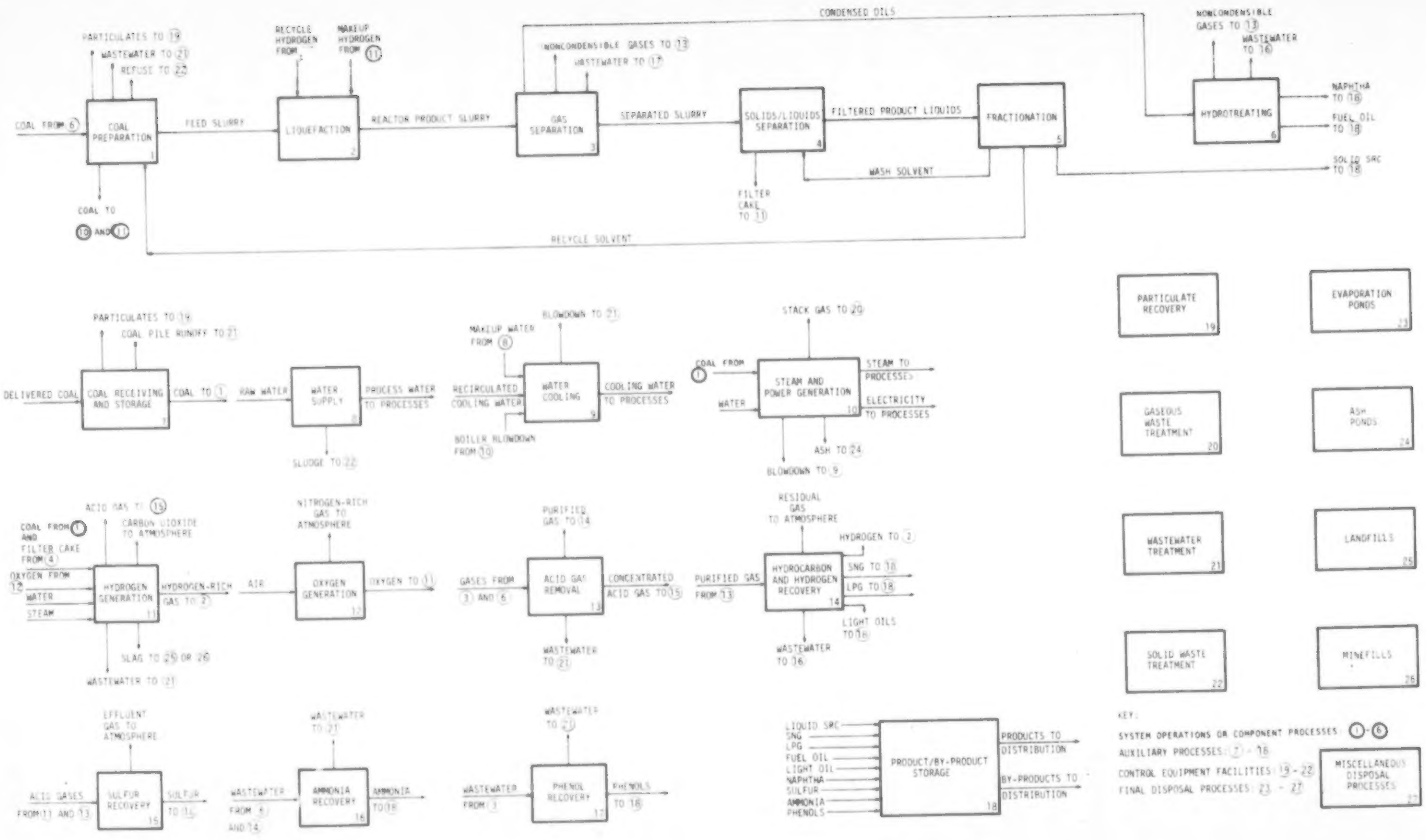

PARTICULATES TO ⑲
WASTEWATER TO ㉑
REFUSE TO ㉒
COAL FROM ⑥
COAL PREPARATION 1
COAL TO ⑩ AND ⑪
FEED SLURRY
RECYCLE HYDROGEN FROM
MAKEUP HYDROGEN FROM ⑪
LIQUEFACTION 2
REACTOR PRODUCT SLURRY
NONCONDENSIBLE GASES TO ⑬
WASTEWATER TO ⑰
GAS SEPARATION 3
SEPARATED SLURRY
SOLIDS/LIQUIDS SEPARATION 4
FILTER CAKE TO ⑪
FILTERED PRODUCT LIQUIDS
WASH SOLVENT
FRACTIONATION 5
CONDENSED OILS
RECYCLE SOLVENT
NONCONDENSIBLE GASES TO ⑬
WASTEWATER TO ⑯
HYDROTREATING 6
NAPHTHA TO ⑱
FUEL OIL TO ⑱
SOLID SRC TO ⑱
PARTICULATES TO ⑲
COAL PILE RUNOFF TO ㉑
DELIVERED COAL
COAL RECEIVING AND STORAGE 7
COAL TO ①
RAW WATER
WATER SUPPLY 8
PROCESS WATER TO PROCESSES
SLUDGE TO ㉒
MAKEUP WATER FROM ⑧
BLOWDOWN TO ㉑
RECIRCULATED COOLING WATER
WATER COOLING 9
COOLING WATER TO PROCESSES
BOILER BLOWDOWN FROM ⑩
STACK GAS TO ⑳
COAL FROM ①
WATER
STEAM AND POWER GENERATION 10
STEAM TO PROCESSES
ELECTRICITY TO PROCESSES
ASH TO ㉔
BLOWDOWN TO ⑨
ACID GAS TO ⑮
CARBON DIOXIDE TO ATMOSPHERE
COAL FROM ① AND FILTER CAKE FROM ④
OXYGEN FROM ⑫
WATER
STEAM
HYDROGEN GENERATION 11
HYDROGEN-RICH GAS TO ②
SLAG TO ㉕ OR ㉖
WASTEWATER TO ㉑
AIR
NITROGEN-RICH GAS TO ATMOSPHERE
OXYGEN GENERATION 12
OXYGEN TO ⑪
PURIFIED GAS TO ⑭
GASES FROM ③ AND ⑥
ACID GAS REMOVAL 13
CONCENTRATED ACID GAS TO ⑮
WASTEWATER TO ㉑
RESIDUAL GAS TO ATMOSPHERE
PURIFIED GAS FROM ⑬
HYDROCARBON AND HYDROGEN RECOVERY 14
HYDROGEN TO ②
SNG TO ⑱
LPG TO ⑱
LIGHT OILS TO ⑱
WASTEWATER TO ⑯
EFFLUENT GAS TO ATMOSPHERE
ACID GASES FROM ⑪ AND ⑬
SULFUR RECOVERY 15
SULFUR TO ⑱
WASTEWATER FROM ③ AND ⑭
WASTEWATER TO ㉑
AMMONIA RECOVERY 16
AMMONIA TO ⑱
WASTEWATER FROM ③
WASTEWATER TO ㉑
PHENOL RECOVERY 17
PHENOLS TO ⑱
LIQUID SRC
SNG
LPG
FUEL OIL
LIGHT OIL
NAPHTHA
SULFUR
AMMONIA
PHENOLS
PRODUCT/BY-PRODUCT STORAGE 18
PRODUCTS TO DISTRIBUTION
BY-PRODUCTS TO DISTRIBUTION
PARTICULATE RECOVERY 19
GASEOUS WASTE TREATMENT 20
WASTEWATER TREATMENT 21
SOLID WASTE TREATMENT 22
EVAPORATION PONDS 23
ASH PONDS 24
LANDFILLS 25
MINEFILLS 26
MISCELLANEOUS DISPOSAL PROCESSES 27
KEY:
SYSTEM OPERATIONS OR COMPONENT PROCESSES ①-⑥
AUXILIARY PROCESSES ⑦ - ⑱
CONTROL EQUIPMENT FACILITIES ⑲ - ㉒
FINAL DISPOSAL PROCESSES ㉓ - ㉗

Figure 14. Generalized flow diagram of SRC-I system.

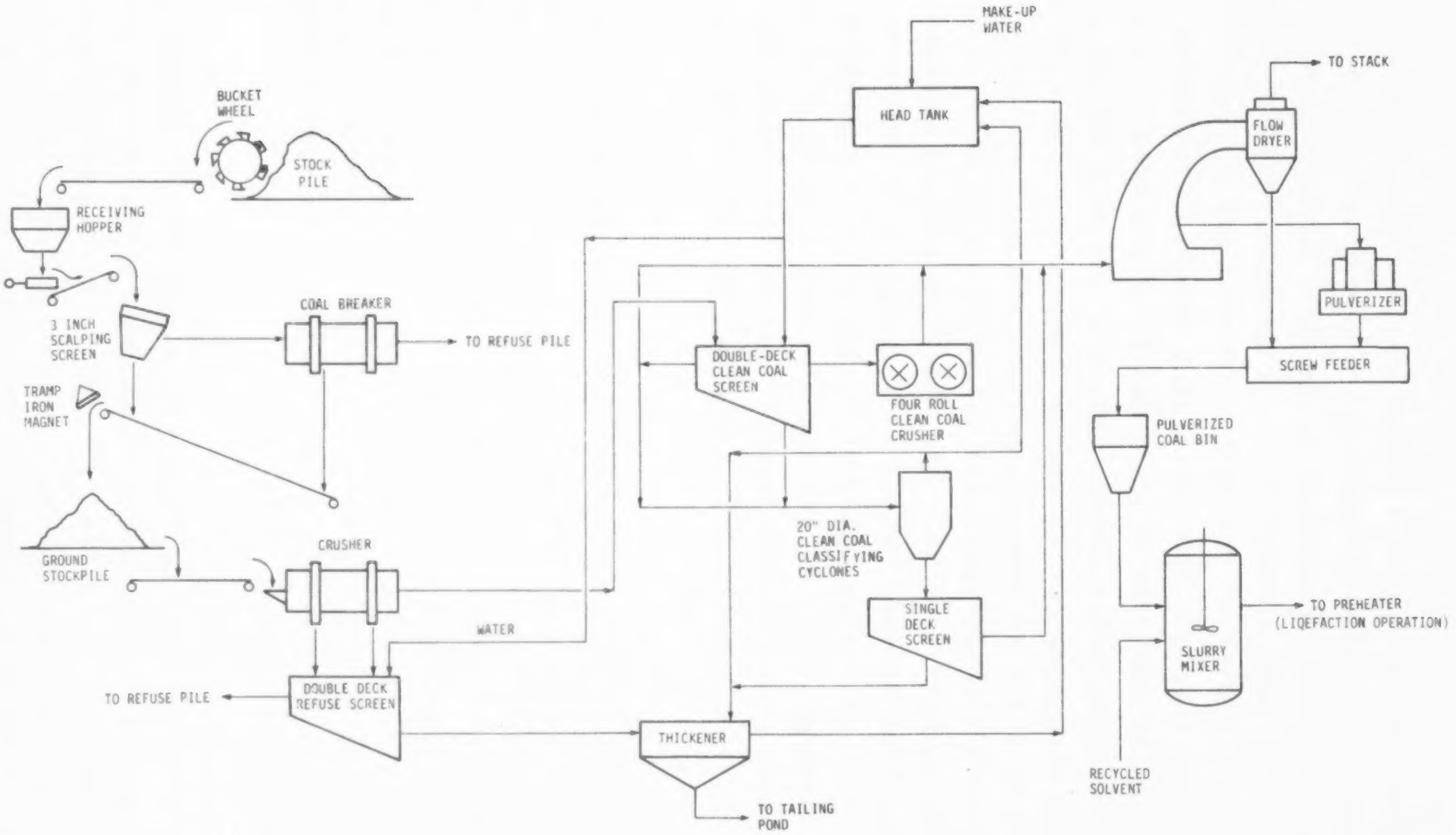

MAKE-UP WATER
TO STACK
BUCKET WHEEL
HEAD TANK
FLOW DRYER
STOCK PILE
RECEIVING HOPPER
PULVERIZER
COAL BREAKER
3 INCH SCALPING SCREEN
TO REFUSE PILE
DOUBLE-DECK CLEAN COAL SCREEN
SCREW FEEDER
TRAMP IRON MAGNET
FOUR ROLL CLEAN COAL CRUSHER
PULVERIZED COAL BIN
GROUND STOCKPILE
CRUSHER
20" DIA. CLEAN COAL CLASSIFYING CYCLONES
SINGLE DECK SCREEN
TO PREHEATER (LIQEFACTION OPERATION)
WATER
SLURRY MIXER
TO REFUSE PILE
DOUBLE DECK REFUSE SCREEN
THICKENER
RECYCLED SOLVENT
TO TAILING POND

Figure 15. Process modules of coal receiving, storage, and pretreatment facilities

ceiving and storage facilities are also shown. Coal is reclaimed from the coal receiving and storage area by a bucket-wheel which feeds the coal going to a transverse conveyor to one or two belt conveyors. A transverse conveyor takes the coal from either of the belt conveyors and delivers it to a receiving hopper. The reclaiming system will handle up to 1,182 Mg of coal per hour. Coal is discharged to a 1.5 m reciprocating plate feeder onto a 1.2 m belt driven conveyor, fitted with a magnet to remove tramp iron. The coal is conveyed to a 7.6 cm scalping screen, which separates out oversize coal (7.6 cm plus) and allows broken coal (7.6 cm minus) to pass through. The oversize coal is charged to a rotary coal breaker, where it is crushed to less than 7.6 cm. Oversize refuse present in the coal is separated in the coal breaker. The broken coal is placed on a 1.2 m belt conveyor, where it is combined with the undersize coal from the scalping screens and discharged to a 9,100 Mg storage pile (6).

The raw coal stockpile of coal receiving and storage and the broken coal storage pile of the coal pretreatment operation provide a total storage capacity of approximately 95,055 Mg of coal. A polymer coating may be applied to each pile to minimize oxidation. Most rainfall coming in contact with coated storage piles will run off while only a small percentage will infiltrate. Assuming a storage pile is conical and 7.6 m tall, its total area has been calculated to be approximately 33 Km^2 (6).

Coal is withdrawn from the minus 7.6 cm, ground coal storage pile and conveyed to the washing plant for cleaning and reduction. A series of jigs, screens, centrifuges, cyclones, and roll crushers clean the coal and reduce it to minus .3 mm in pulverizers. The pulverized coal is suitable for slurry feed mixing.

The dried, pulverized coal is transferred by conveyor to the coal/solvent tank, in which 18,182 mg of coal and 36,364 mg of unfiltered slurry are mixed per day. The feed slurry is then pumped to the preheater.

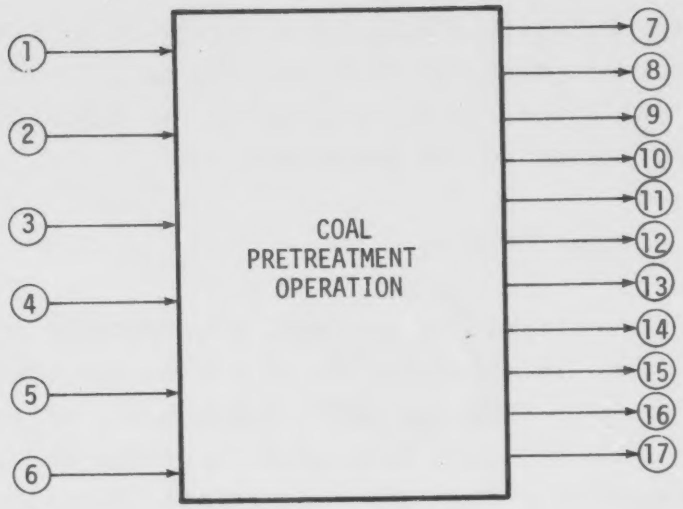
2.2.2.1 Input Streams

A block flow diagram of the coal pretreatment operation is shown in Figure 16. Quantities indicated for the streams are based on an SRC-II design (6). Major input streams identified include raw coal from coal receiving and storage, recycle process slurry from the separations operation, air used to dry the coal, and makeup water for coal cleaning. Stream 2, recycled process slurry, would be recycled process solvent if SRC-I operation was assumed.

2.2.2.2 Output Streams

Output streams, including waste streams, exiting the coal pretreatment operation are also shown in Figure 16. No major variation in stream characteristics or quantities would be expected if SRC-I operation was assumed. Key output streams are described below.

- Dust from coal sizing processes - The dust consists of coal particles, typically one to 100 microns in size, with composition similar to that of the parent coal. The SRC-II material balance (6) is based on Illinois No. 6 seam coal. Proximate and ultimate analyses of Illinois No. 6 coal can be found in Table 9, an ash analysis is presented in Table 10. Data in Table 11 suggest that coal dust will contain significant concentrations of the trace elements titanium, magnesium, boron, fluorine, zinc, and barium.



	STREAM	QUANTITY (Mg/day)
1.	COAL FROM STORAGE STOCKPILE	29732
2.	RECYCLE PROCESS SLURRY	36364
3.	AIR TO COAL DRYERS	29827
4.	MAKEUP WATER	2028
5.	FUEL GAS/AIR MIXTURE	3601
6.	MOISTURE FROM ENVIRONMENT	60.6
7.	COAL DUST	15
8.	TRAMP IRON/REFUSE	1495
9.	REFUSE FROM CLEANING PROCESSES	6217
10.	COAL PILE RUNOFF	60.6
11.	THICKENER UNDERFLOW (35% SOLIDS)	3120
12.	COAL TO HYDROGEN PRODUCTION (2% MOISTURE)	1392
13.	COAL TO STEAM GENERATION (2% MOISTURE)	940
14.	FEED SLURRY TO LIQUEFACTION	54916
15.	DRYER STACK GAS	29856
16.	GLAND WATER	NOT QUANTIFIABLE
17.	FLUE GAS	3601

Figure 16. Block flow diagram of coal pretreatment operation (SRC-II mode)

TABLE 9. RUN OF MINE (ROM) ILLINOIS NO. 6 COAL ANALYSIS (14)

Proximate analysis (weight percent):		
Moisture	2.70	
Ash	7.13	
Volatile matter	38.47	
Fixed carbon	51.70	
Heating value	30 MJ/kg	
Ultimate analysis (weight percent):		
Carbon	70.75	
Hydrogen	4.69	
Nitrogen	1.07	
Sulfur	3.38	
Oxygen	10.28	
Total	90.17	(balance is moisture and ash, as shown in proximate analysis)

TABLE 10. AVERAGE ASH ANALYSIS OF ILLINOIS NO. 6 COAL (19)

Component	Percent of Ash
SiO_2	44.4
Al_2O_3	21.0
Fe_2O_3	22.1
TiO_2	1.1
P_2O_5	0.1
CaO	5.2
MgO	1.0
Na_2O	0.5
K_2O	2.0
SO_3	1.7
Others (not specified)	0.9
Total	100.0

TABLE 11. TRACE ELEMENT COMPOSITION OF ILLINOIS NO. 6 COAL SAMPLES (20)

Element	Concentration, ppm (wt. basis)
Aluminum	13,500
Antimony	0.98
Arsenic	5.9
Barium	111
Beryllium	1.5
Boron	135
Bromine	15
Cadmium	<4
Calcium	7690
Cerium	13
Cesium	1.2
Chlorine	1600
Chromium	20
Cobalt	6.6
Copper	13
Dysprosium	1.0
Europium	0.25
Fluorine	63
Gallium	3.1
Germanium	<5.6
Hafnium	0.52
Indium	0.14
Iodine	1.9
Iron	18,600
Lanthanum	7
Lead	27
Lutetium	0.08
Magnesium	510
Manganese	53
Mercury	0.18
Molybdenum	9.2
Nickel	22
Phosphorus	45
Potassium	1700
Rubidium	16
Samarium	1.2
Scandium	2.6
Selenium	2.2
Silicon	26,800
Silver	0.03
Sodium	660
Strontium	36

(continued)

TABLE 11. (continued)

Element	Concentration, ppm (wt. basis)
Tantalum	0.16
Terbium	0.17
Thallium	0.67
Thorium	2.2
Tin	4.7
Titanium	700
Tungsten	0.7
Uranium	1.6
Vanadium	33
Ytterbium	0.54
Zinc	420
Zirconium	52

- Coal pile runoff - Coal pile runoff results from rainfall and infiltration waters that come into contact with the stored coal. The resulting leachate may contain oxidation products of metalic sulfides; it is frequently acidic, with relatively high concentrations of suspended and dissolved solids, sulfate, iron, calcium, and other coal constituents. The quantity and concentration of coal pile runoff water generated is dependent on the type of coal used; the history of the pile; and the rate, duration, frequency, and pH of precipitation.

  Assuming a stormwater runoff coefficient of 0.7, the mass flow rate of coal pile runoff waters has been calculated to be 67 Mg/day. This figure includes runoff from the coal receiving and storage stockpile and the storage pile in the coal preparation operation. This quantity of runoff is based on the average annual rainfall (108 cm/yr) for the state of Illinois (a likely location for SRC plants) and the total coal storage area (33 Km^2), (22,23).

- Refuse from reclaiming and crushing - Refuse from the reclaiming and crushing processes is composed chiefly of tramp iron, slate, coal and "bone." These materials are naturally present in the coal seam. Particle size is greater than 7.6 cm.

- Refuse from pulverizing and drying - This refuse stream is generated after screening with the double deck refuse screen. The stream contains slate, coal, and water added during screening. Both refuse streams are stockpiled before final disposal.

- Thickener underflow - Wastewater generated from a number of processes in the coal pretreatment operation is routed to a thickener where particulates are removed and clarified water is recycled. The underflow stream has a flow of 3,120 Mg/day, with a suspended solids loading of 1,092 Mg/day which corresponds to a concentration of 35 percent suspended solids. The wastewater is expected to contain a substantial quantity of coal-derived organic constituents prior to wastewater treatment.

- Gland water - Gland water is generated from leaks in the piping system; hence, it has not been quantified. It may contain substantial concentrations of particulate and organic matter. Gland water may be collected in a sump and pumped to treatment.

- Gaseous emission from drying - This waste stream has been calculated to carry 2,983 Mg/day of moisture and 29 Mg/day of particulates for the SRC-II plant (6). A significant concentration of coal-derived organics is also expected to be present in this stream. Gas from fuel combustion is composed of carbon dioxide, water, carbon monoxide, nitrogen, oxygen and unreacted hydrocarbons.

2.2.3 Liquefaction

A process module diagram of the liquefaction operation is shown in Figure 17.

In the liquefaction operation, the resultant coal/slurry mixture from coal pretreatment is first injected with hydrogen gas. The hydrogen gas is a mixture of recycle hydrogen and synthesis gas from the hydrogen production module and has a total hydrogen content of 97 percent by volume. The gas/slurry stream is pumped to a dissolver preheater elevating the pressure to about 11.9 MPa. The preheater increases the temperature to approximately 454°C. The preheater is fired by fuel gas (6,14).

The heated mixture is then introduced into a dissolver where the coal is depolymerized and hydrogenated. The solvent is hydrocracked to form hydrocarbons of lower molecular weight, ranging from light oil to methane; organic sulfur is hydrogenated to form hydrogen sulfide. The temperature and pressure in the dissolver are about 454°C and 11.7 MPa, respectively (6,14).

The resultant product stream contains gases, liquids, and solids. It is removed from the dissolver reactor and

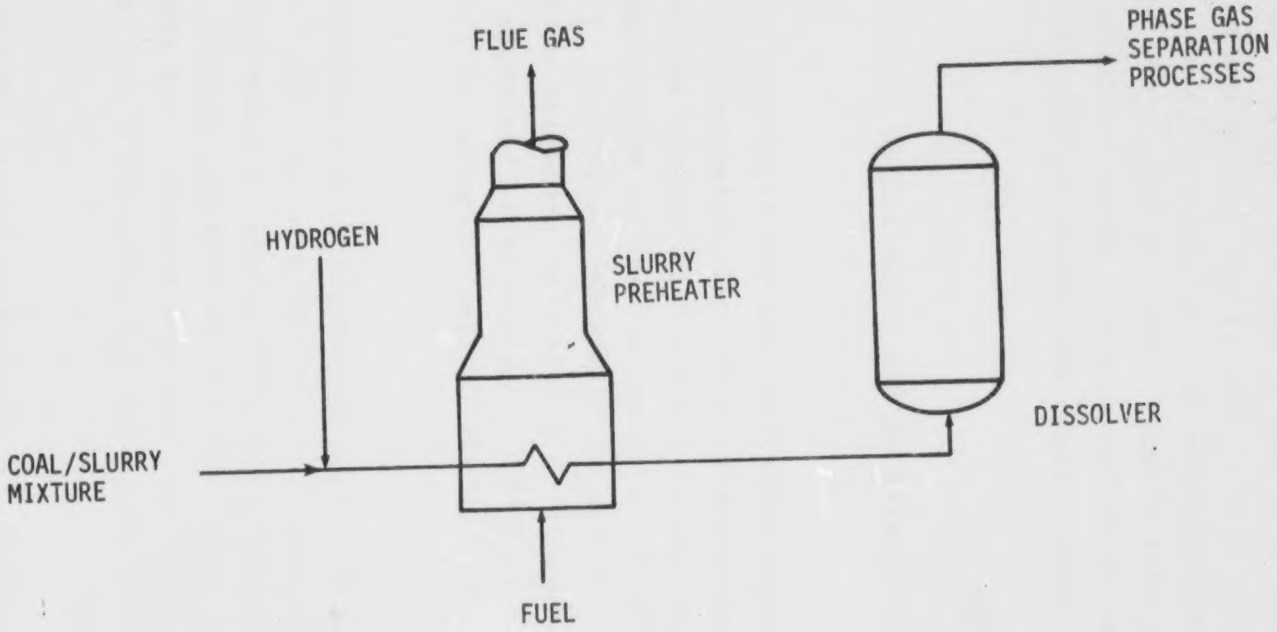

FLUE GAS
PHASE GAS SEPARATION PROCESSES
HYDROGEN
SLURRY PREHEATER
DISSOLVER
COAL/SLURRY MIXTURE
FUEL

Figure 17. Process module diagram of the coal liquefaction operation

transferred to a series of vessels to separate various products.

2.2.3.1 Input Streams

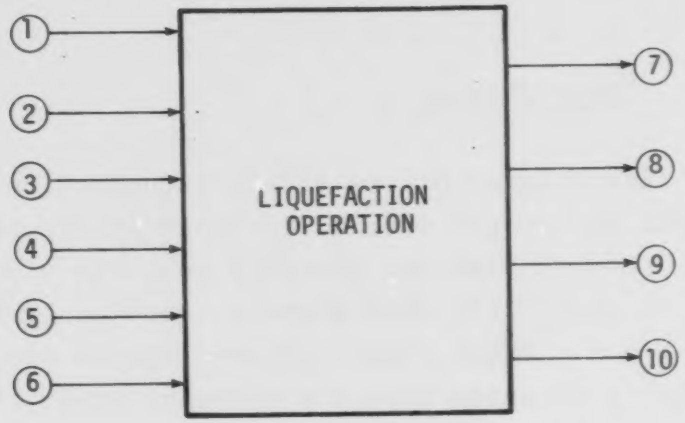
A block flow diagram of the SRC-II liquefaction operation with input and output streams is shown in Figure 18. Input streams' composition and quantity would be similar for SRC-I operation except the feed mixture, previously discussed in Section 2.2.2.1. Other input streams include process water, hydrogen-rich gases from the hydrogen production and hydrocarbon/hydrogen recovery processes, and fuel and air to the preheater.

2.2.3.2 Output Streams

There are four output streams associated with the liquefaction operation. The reactor product slurry passes to the gas separation process for additional processing. Table 12 summarizes the estimated composition of the reactor product slurry.

TABLE 12. COMPOSITION OF LIQUEFACTION
REACTOR PRODUCT SLURRY

Constituent	Quantity, Mg/day
Liquid product	44,675
Residue and ash	2,784
Light and heavy oils	3,174
Hydrogen sulfide	426
Ammonia	55
Nitrogen	17
Carbon monoxide	361
Carbon dioxide	263
Unconsumed hydrogen	513
Water	3,042
Gaseous hydrocarbons	3,224



STREAM	QUANTITY (Mg/day)
1. FEED SLURRY	54916
2. WATER	2411
3. SYNTHESIS GAS FROM HYDROGEN PRODUCTION	667
4. HYDROGEN FROM HYDROCARBON/HYDROGEN RECOVERY	538
5. FUEL GAS TO PREHEATER	691
6. AIR TO PREHEATER	12725
7. LIQUEFACTION REACTOR EFFLUENT	58532
8. PREHEATER FLUE GAS	13416
9. VAPOR DISCHARGE	NOT QUANTIFIABLE
10. ACCIDENTAL MATERIAL SPILLS	NOT QUANTIFIABLE

Figure 18. Block flow diagram of liquefaction operation (SRC-II Mode)

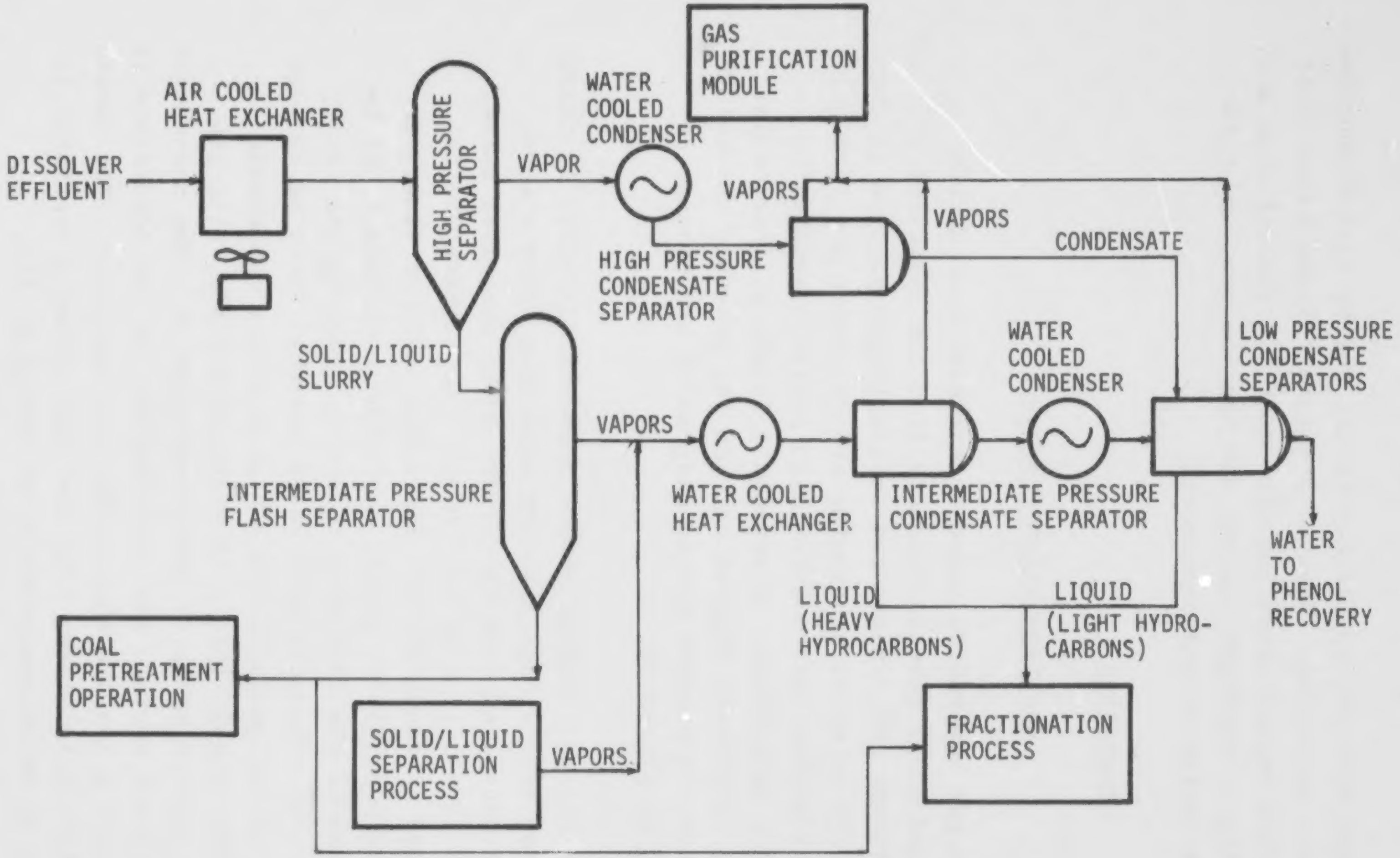
Accidental material spills may result during system shutdown or reactor servicing. Reactor pressure release values emit hydrocarbon vapors requiring treatment. Preheater flue gas, consisting of nitrogen, carbon dioxide, oxygen, and water vapor is vented to the atmosphere.

2.2.4 Separation

2.2.4.1 Gas Separation Process

The gas separation process separates hydrocarbon vapors and other gaseous products from the dissolver effluent slurry stream and directs the solids/liquid portion of the coal slurry to other processing areas. There are five unit processes within this module: high pressure separation, condensate separation, intermediate flashing, intermediate pressure condensate separation, and low pressure condensate separation. A process module diagram of the process is provided in Figure 19.

The reactor product slurry from the dissolver is first introduced into a high pressure separator where the hot vapor is separated from the slurry under dissolver outlet pressure (i.e., 11.4 to 11.7 MPa). The temperature is maintained at about 292°C. Since the influent slurry is usually around 454°C, an air cooled heat exchanger may be used ahead of the separator to aid in reducing the slurry temperature. The separated gases are then directed through a water cooled condenser to a high pressure condensate separation vessel along with hydrogen sulfide, nitrogen, ammonia, carbon monoxide and carbon dioxide. The uncondensed vapors are sent to gas purification and the condensate is directed to a low pressure condensate separator. The remaining solid/liquid slurry from the high pressure separator is directed to an intermediate flash vessel (6,24).



DISSOLVER EFFLUENT
AIR COOLED HEAT EXCHANGER
HIGH PRESSURE SEPARATOR
VAPOR
WATER COOLED CONDENSER
GAS PURIFICATION MODULE
VAPORS
VAPORS
HIGH PRESSURE CONDENSATE SEPARATOR
CONDENSATE
SOLID/LIQUID SLURRY
WATER COOLED CONDENSER
LOW PRESSURE CONDENSATE SEPARATORS
VAPORS
INTERMEDIATE PRESSURE FLASH SEPARATOR
WATER COOLED HEAT EXCHANGER
INTERMEDIATE PRESSURE CONDENSATE SEPARATOR
WATER TO PHENOL RECOVERY
LIQUID (HEAVY HYDROCARBONS)
LIQUID (LIGHT HYDRO-CARBONS)
COAL PRETREATMENT OPERATION
SOLID/LIQUID SEPARATION PROCESS
VAPORS
FRACTIONATION PROCESS

Figure 19. Process modules of gas separation process (SRC-II mode).

The solid/liquid slurry from the high pressure flash separator enters an intermediate flashing vessel where the pressure is descreased to approximately 3.4 MPa under a constant temperature of 292°C (6,24). The reduced pressure vaporizes numerous hydrocarbons which are discharged to the intermediate pressure condensate separator. The remaining slurry, consisting mostly of original solvent, dissolved coal, and undissolved coal solids, is split into two streams. The majority of the slurry flow is recycled back to the coal preparation operation. The remaining slurry is routed to the fractionation operation. If SRC-I operation is assumed, all slurry is sent to the solids/liquids separation process. Process-derived solvent, used for slurry preparation in SRC-I, is recovered during fractionation of the filtered product liquids.

The vapors from the intermediate pressure flash separators are directed through a water cooled condenser prior to entering the intermediate pressure condensate separator. Heavier-than-water hydrocarbons are separated from water and lighter hydrocarbons and routed to the fractionation process. Uncondensed gases are directed to the acid gas removal process. The water and light hydrocarbon stream is combined with the vapor stream from the filter feed flash unit (solids/liquids separation) and the gas-liquid stream flows through another condenser. The condensed mixture is charged to a low pressure condensate separator in which the hydrocarbon, water, and gaseous phases are separated. The light hydrocarbons are routed to fractionation process. Sour water is directed to by-product recovery processes. The uncondensible gases flow to the gas purification module for the removal of hydrogen sulfide and carbon dioxide.

2.2.4.1.1 Input Streams

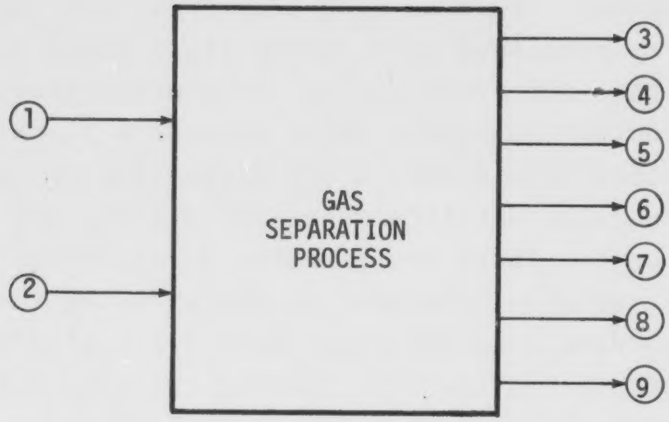
Two input streams are associated with gas separation. The major input stream is the reactor product slurry exiting the dissolver of the liquefaction operation. The other input stream is composed of flash gases from solids/liquids separation. A block flow diagram of gas separation, with input and output streams is shown in Figure 20.

2.2.4.1.2 Output Streams

Seven output streams are shown in Figure 20. The solids/ liquids slurry exiting the operation is split into two streams. Part of the slurry is sent to fractionation, as are oils condensed during the flashing process. The majority of the stream is recycled to coal pretreatment. Flashed gases are sent to an auxiliary process which recovers the valuable hydrogen and hydrocarbon constituents from the mixture. A sour water stream is generated and sent to phenol and ammonia recovery processes. Other output streams consist of vapor discharges and material spills.

2.2.4.2 Solids/Liquids Separation Process

The objective of solids/liquids separation is to remove mineral matter, char and unreacted coal from the product slurry, thereby yielding liquid products. Numerous approaches have been considered to meet this objective including filtration, vacuum distillation, centrifugation and solvent deashing. Recent SRC-I and SRC-II conceptual designs specify utilization of filtration and vacuum distillation respectively to perform solids/liquids separation.



	STREAM	QUANTITY (Mg/day)
1.	REACTOR PRODUCT SLURRY FROM LIQUEFACTION	58532
2.	FLASHED GASES FROM SOLIDS/LIQUIDS SEPARATION	943
3.	SOLIDS/LIQUID SLURRY TO FRACTIONATION	12037
4.	GASES TO ACID GAS REMOVAL	4799
5.	CONDENSED OILS TO FRACTIONATION	3140
6.	SOUR WATER	3135
7.	VAPOR DISCHARGE	NOT QUANTIFIABLE
8.	ACCIDENTAL MATERIAL SPILLS	NOT QUANTIFIABLE
9.	RECYCLE SLURRY TO COAL PRETREATMENT	36364

Figure 20. Block flow diagram of gas separation process (SRC-II mode)

The following description is applicable to SRC-II liquefaction. A process flow schematic of the operation is shown in Figure 21. Concentrated slurry from fractionation is charged to a feed flash vessel. Flashed gases are returned to gas separation. The remaining slurry exiting the feed flash vessel is processed in a vacuum still which removes additional liquid SRC product from the slurry, leaving a high-solids content residue. After secondary flashing to remove additional liquid SRC, a solidification process is employed to cool the hot liquid residue exiting the vacuum distillation unit. There are a number of different solidification units available, the most promising being the metal belt, rotating drum, and rotating shelf types (6,17). The solidification process involves feeding the liquid stream onto a moving heat transfer surface. Cooling water is sprayed on the other side of the heat transfer surface to initiate cooling. Additional cooling may be provided by passing refrigerated air over the product stream (6,17). The cooled solid residue is scraped off the heat transfer surface with a knife and is transferred to hydrogen generation and/or disposal by screw conveyor. Figure 22 shows schematics of two types of solidification units.

Several differences should be noted if SRC-I operation is assumed. Solids/liquids separation would be performed prior to fractionation. Filtration rather than vacuum distillation would be utilized. A wash solvent, derived from fractionation of raw SRC product liquids would be used in the filtration process. Collected solids would be in the form of filter cake rather than a hot residue. A solidification process of greater capacity would be required as part of the SRC-I fractionation operation to cool SRC-I product, a solid at ambient conditions.

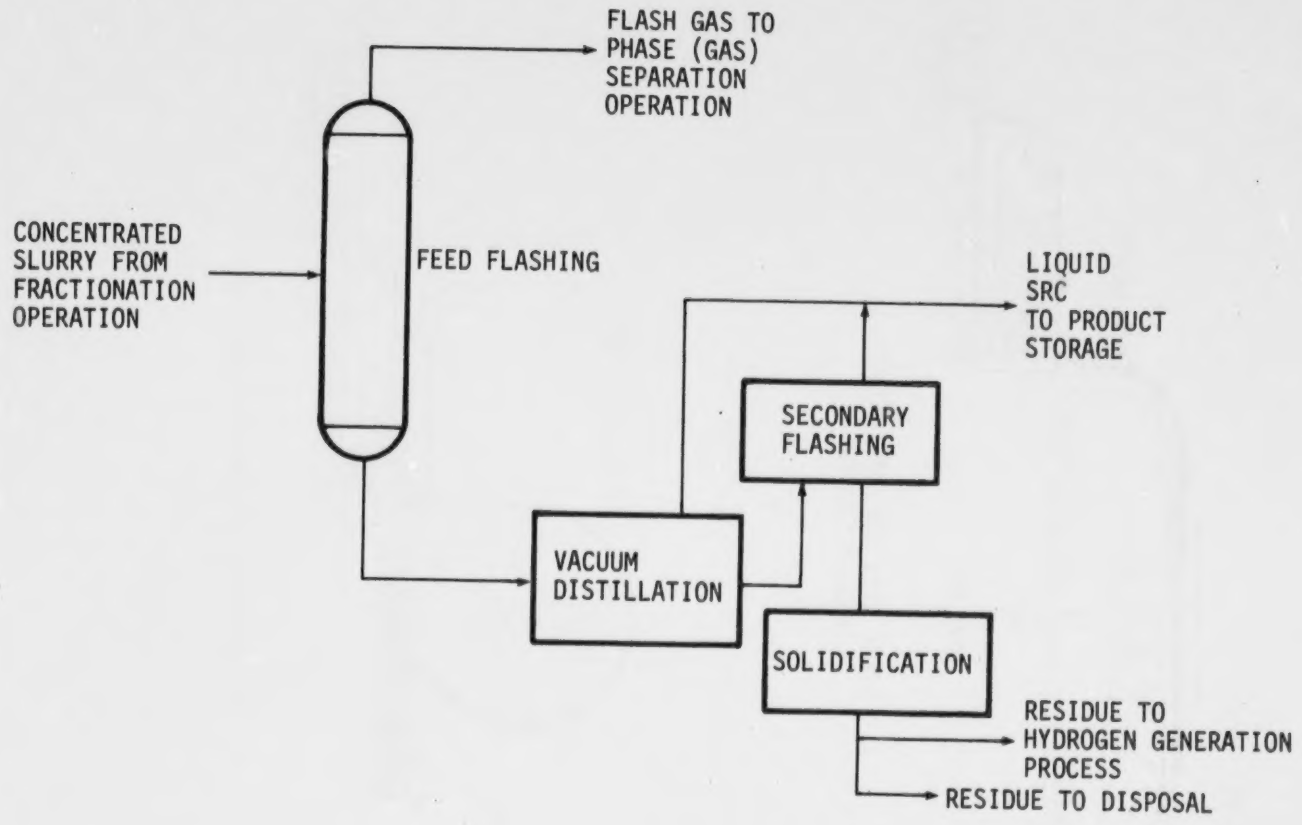
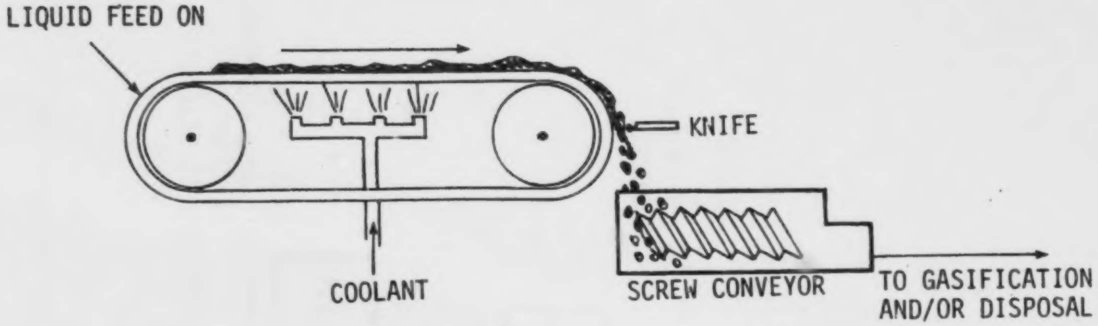
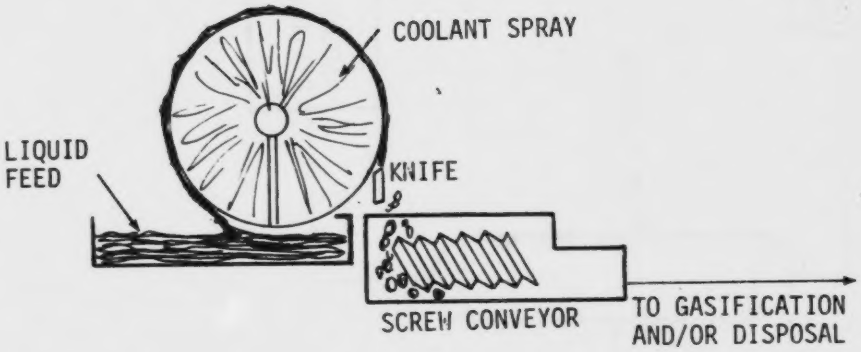

FLASH GAS TO
PHASE (GAS)
SEPARATION
OPERATION
CONCENTRATED
SLURRY FROM
FRACTIONATION
OPERATION
FEED FLASHING
LIQUID
SRC
TO PRODUCT
STORAGE
SECONDARY
FLASHING
VACUUM
DISTILLATION
SOLIDIFICATION
RESIDUE TO
HYDROGEN GENERATION
PROCESS
RESIDUE TO DISPOSAL

Figure 21. Process flow schematic: solids/liquids separation process (SRC-II mode)


LIQUID FEED ON
KNIFE
COOLANT
SCREW CONVEYOR
TO GASIFICATION AND/OR DISPOSAL

I. STEEL BELT SOLIDIFICATION
(SANDVIK SYSTEM)


COOLANT SPRAY
LIQUID FEED
KNIFE
SCREW CONVEYOR
TO GASIFICATION AND/OR DISPOSAL

II. ROTARY DRUM SOLIDIFICATION

Figure 22. Two solidification alternatives

2.2.4.2.1 Input Streams

The major input to solids/liquids separation (Figure 23) is the bottom stream produced in the fractionation operation. Fuel gas and air is used to fire the preheater. Input cooling water is used in the solidification process.

2.2.4.2.2 Output Streams

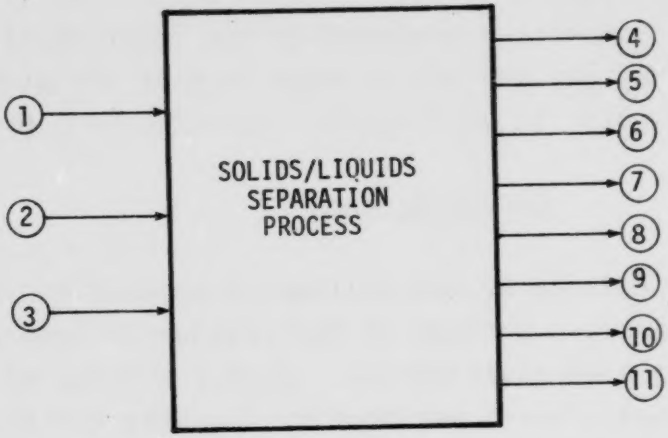
Residue produced by solids/liquids separation is divided into two streams. A portion of the residue is used to produce hydrogen by gasification. Excess residue will require disposal. Gases produced by flashing are returned to gas separation. Liquid SRC produced by solids/liquids separation is collected and stored as a product. Other output streams are preheater flue gas, vapor losses (particularly from the solidification process), accidental material spills and output cooling water.

2.2.5 Purification and Upgrading

2.2.5.1 Fractionation

The main functions of fractionation in SRC-II operation are: (1) to separate the high boiling liquid SRC product from lower boiling fractions; (2) to combine low boiling fractions for hydrotreating into light products; and (3) to produce a bottom stream of high solids control for solids/ liquids separation.

In commercial SRC-I designs solids/liquids separation is performed prior to fractionation. Vacuum distillation and filtration, the respective solids/liquids separation methods for SRC-II and SRC-I have been described in the pre-


SOLIDS/LIQUIDS SEPARATION PROCESS
1
2
3
4
5
6
7
8
9
10
11

STREAM	QUANTITY (Mg/day)
1. BOTTOMS FROM FRACTIONATION	9311
2. FUEL GAS AND AIR	4537
3. COOLING WATER INPUT	NOT QUANTIFIED
4. RESIDUE TO HYDROGEN GENERATION	1364
5. EXCESS RESIDUE TO DISPOSAL	4203
6. FLUE GAS	4537
7. FLASH GAS	943
8. LIQUID SRC	2801
9. COOLING WATER OUTPUT	NOT QUANTIFIED
10. VAPOR LOSSES	NOT QUANTIFIABLE
11. ACCIDENTAL MATERIAL SPILLS	NOT QUANTIFIABLE

Figure 23. Block flow diagram of solids/liquids separation process. (SRC-II Mode)

ceding subsection. The functions of fractionation in SRC-I are to: (1) separate SRC product (solid at ambient conditions) from lower boiling fractions; (2) recover a solvent fraction for recycling to coal pretreatment; (3) to combine light streams for hydrotreating; and (4) to recover a wash solvent employed in the filtration process used for solids/liquids separation in SRC-I.

The following description of the fractionation process is applicable to the SRC-II mode. Separated slurry exiting gas separation passes through a gas-fired preheater in which it is heated to a temperature of 427° to 467°C (6,13). The hot stream is charged to a vacuum flash drum, in which lighter fractions are separated from high-boiling slurry constituents. The light fractions are combined with condensed oils from gas separation. Fractionator products consist of raw naphtha and fuel oil, SRC liquid, and the fractionator bottoms (concentrated slurry which is sent to solids/liquids separation). A schematic illustration of fractionation is provided in Figure 24.

2.2.5.1.1 Input Streams

Input and output streams associated with the fractionation process are shown in Figure 25. Two of the inputs, separated slurry and condensed oils, are received from gas separation. Input fuel and air are necessary to operate the preheater.

2.2.5.1.2 Output Streams

As shown in Figure 25, seven output streams exit fractionation. SRC liquid is collected as a product. Raw fuel oil and raw naphtha which may be optionally collected as

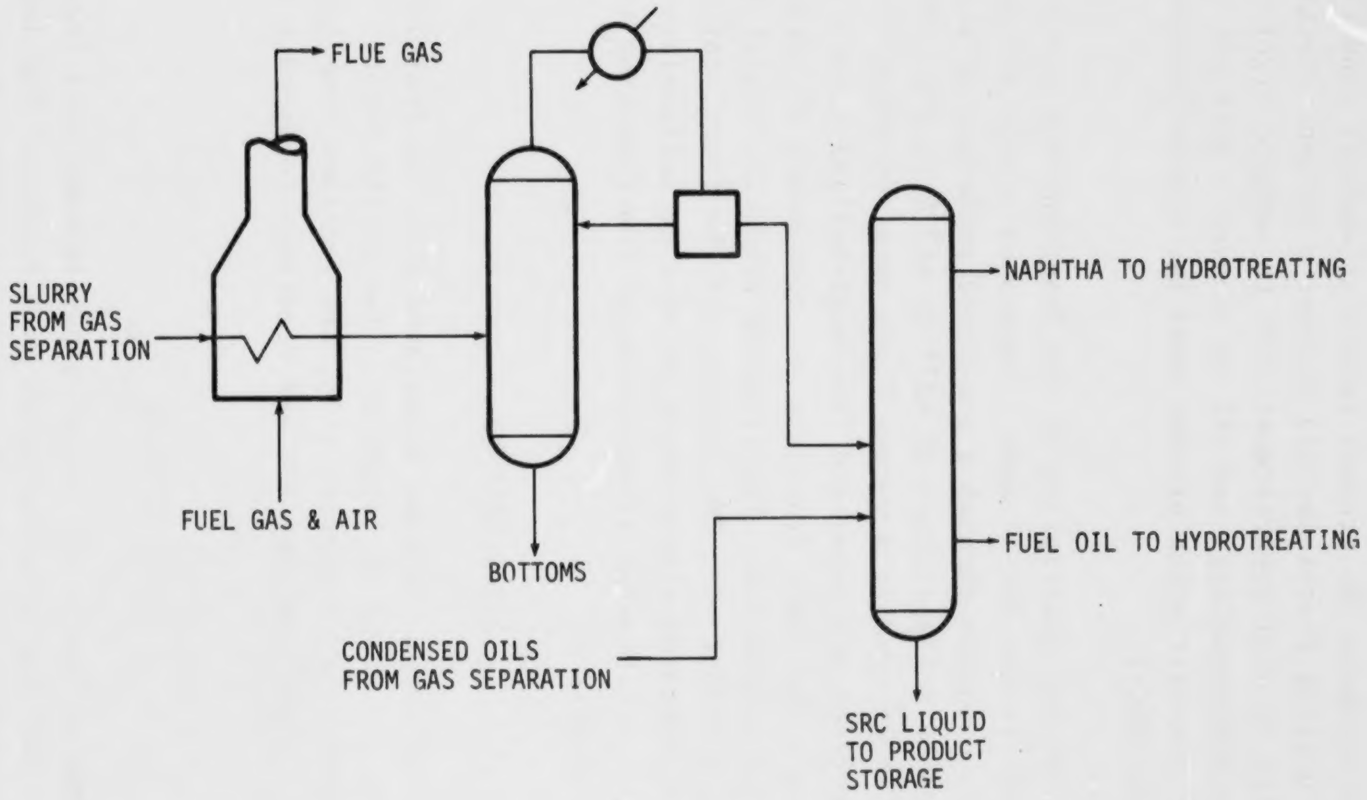
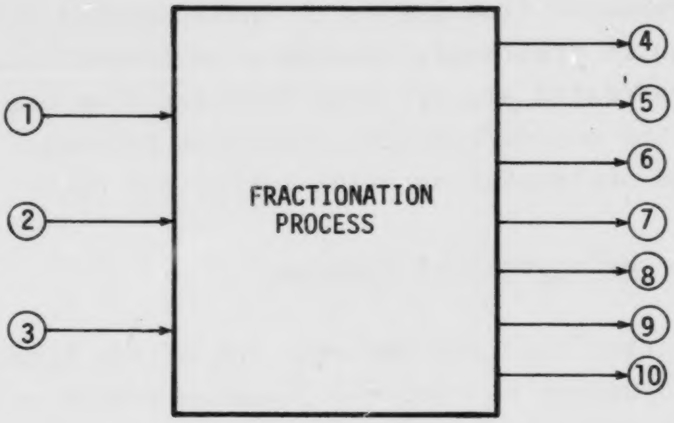

FLUE GAS
SLURRY FROM GAS SEPARATION
FUEL GAS & AIR
BOTTOMS
CONDENSED OILS FROM GAS SEPARATION
NAPHTHA TO HYDROTREATING
FUEL OIL TO HYDROTREATING
SRC LIQUID TO PRODUCT STORAGE

Figure 24. Process flow schematic: fractionation process.
(SRC-II Mode)



STREAM	QUANTITY (Mg/day)
1. SLURRY FROM GAS SEPARATION	12037
2. FUEL GAS AND AIR	7579
3. CONDENSED OILS	3140
4. LIQUID SRC	2726
5. RAW NAPHTHA	525
6. RAW FUEL OIL	2615
7. BOTTOMS	9311
8. PREHEATER FLUE GAS	7579
9. VAPOR DISCHARGE	NOT QUANTIFIABLE
10. ACCIDENTAL MATERIAL SPILLS	NOT QUANTIFIABLE

Figure 25. Block flow diagram of fractionation process. (SRC-II Mode)

products are upgraded by a hydrotreating process. (This report assumes inclusion of raw fuel oil and raw naphtha hydrotreating to permit discussion of pertinent environmental aspects.) Preheater flue gas is an environmental discharge which may require treatment, depending on composition. The bottoms (concentrated slurry) from fractionation are further processed in the solids/liquids separation process. Vapor discharges and accidental material spills may occur.

2.2.5.2 Hydrotreating Process

Hydrotreating involves the reaction of raw hydrocarbon streams with hydrogen to remove contaminants such as organic sulfur and nitrogen compounds, and to improve combustion characteristics so that they may meet commercial specifications. In the process, organic sulfur and nitrogen compounds are converted to hydrogen sulfide and ammonia, which are stripped from the product stream. The hydrogenation reaction also serves to increase the hydrogen-to-carbon ratio, which improves the smoking characteristics of the fuel. It should be noted that hydrotreating may optionally be used in SRC systems; in fact, recent conceptual designs (8) do not specify hydrotreating of SRC products. The hydrotreating option has been retained in this discussion to permit complete environmental assessment.

In the flow schematic shown in Figure 26, raw naphtha and fuel oil streams from fractionation are mixed with synthesis gas from hydrogen generation (85 percent H_2 by volume) and pumped through a gas-fired preheater into an initial catalyst-guard reactor to permit the deposition of any remaining carbon on low surface-to-volume pelletized catalyst in order to prevent plugging of the main hydrotreating reactor. From the guard reactor, the fuel oil or naphtha

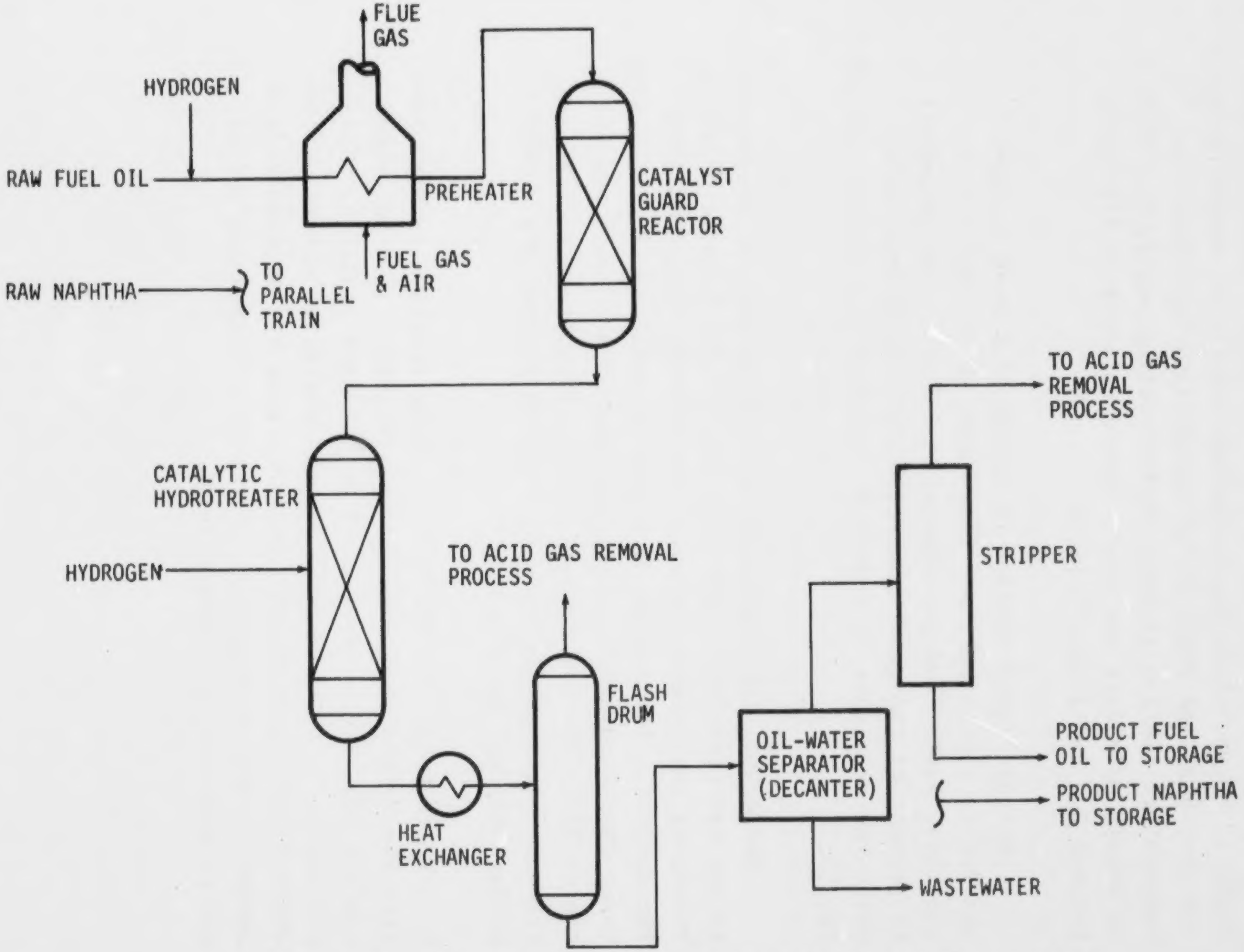

FLUE GAS
HYDROGEN
RAW FUEL OIL
PREHEATER
CATALYST GUARD REACTOR
FUEL GAS & AIR
RAW NAPHTHA
TO PARALLEL TRAIN
TO ACID GAS REMOVAL PROCESS
CATALYTIC HYDROTREATER
HYDROGEN
TO ACID GAS REMOVAL PROCESS
STRIPPER
FLASH DRUM
OIL-WATER SEPARATOR (DECANTER)
PRODUCT FUEL OIL TO STORAGE
PRODUCT NAPHTHA TO STORAGE
HEAT EXCHANGER
WASTEWATER

Figure 26. Process flow schematic hydrotreating process. (SRC-II Mode)

stream is fed into a three section downflow hydrotreating reactor. Quench hydrogen injection points are spaced along the length of the reactors at appropriate locations for temperature control (6,25). Hydrotreating catalysts, such as cobalt molybdate are used. Space velocity is typically between 0.5 and 2 hour^{-1} (6,26).

The gas-liquid product is cooled in a heat exchanger and fed to a high-pressure flash drum where fuel oil (or naphtha), water, and gas separation occurs. Approximately 60 percent of the gas is recycled into the hydrotreaters while the remainder is routed to the acid gas removal process (6,25).

About half the separated fuel oil or naphtha is recycled to the hydrotreaters. The remainder is depressurized into a receiving tank where the water fraction is separated from the solvent. The solvent fraction is pumped into a stripping tower where hydrogen sulfide and ammonia are taken off the top (6,25). The gas product of the stripper is sent to gas cleanup. Product fuel oil and naphtha streams are routed to product storage facilities.

Water formed by the hydrotreating reaction is separated from the hydrocarbon phase in the decanter. The water may contain substantial amounts of ammonia and organics. This wastewater is routed to the ammonia stripping column of the ammonia recovery process. Any remaining hydrogen sulfide or ammonia in the main product stream is stripped and the off-gas is routed to gas purification.

2.2.5.2.1 Input Streams

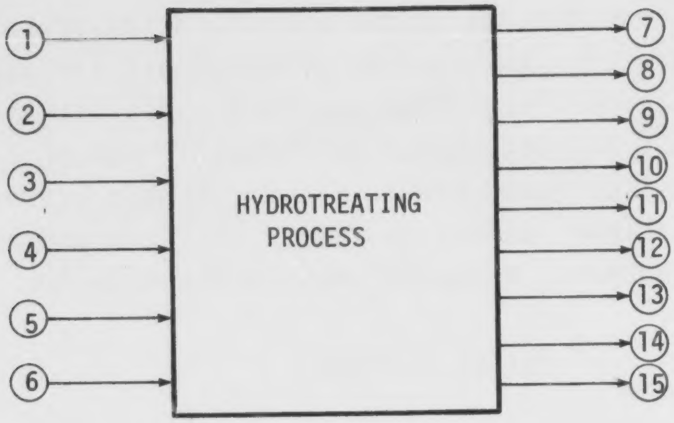
A block flow diagram of the hydrotreating operation is shown in Figure 27. Raw naphtha and fuel oil are inputs as hydrotreater feedstocks. Hydrogen-rich synthesis gas is introduced to react with these feedstocks. Makeup catalyst is added to sulfur guard reactors and the main hydrotreaters to maintain desired product quality. Fuel gas and air are fired in preheaters. Water is used in the decanter.

2.2.5.2.2 Output Streams

Product, process and waste streams are produced during hydrotreating. Products consist of hydrotreated fuel oil and naphtha. Spent catalysts from both sulfur guard and main hydrotreating reactors are solid wastes. (Catalysts from sulfur guard reactors contain significant quantities of carbon residues.) Vapor discharges from pressure vessels and preheater flue gases are air emissions from the process. Wastewater from the decanter, after processing to recover by-products, is sent to wastewater treatment. Accidental material spills will occur occasionally during normal operation of the system. Gases produced by flashing are sent to gas separation.

2.2.6 Auxiliary Processes

This subsection discusses auxiliary processes associated with SRC systems including: coal receiving and storage, water supply, water cooling, steam and power generation, hydrogen production, oxygen production, acid gas removal, hydrogen/hydrocarbon recovery, sulfur recovery, ammonia recovery, phenol recovery, and product/by-product storage.



STREAM	QUANTITY (Mg/day)
1. SYNTHESIS FEED GAS	270
2. RAW NAPHTHA	525
3. RAW FUEL OIL	2615
4. FUEL GAS AND AIR TO PREHEATERS	1543
5. WATER	775
6. CATALYST TO HYDROTREATERS	NOT QUANTIFIED
7. CARBON RESIDUE AND SPENT CATALYST (GUARD REACTORS)	NOT QUANTIFIED
8. SPENT CATALYST (MAIN HYDROTREATERS)	NOT QUANTIFIED
9. DECANTER WASTEWATER	795
10. ACCIDENTAL MATERIAL SPILLS	NOT QUANTIFIABLE
11. PRODUCT FUEL OIL	2591
12. PRODUCT NAPHTHA	518
13. FLASH GAS AND STRIPPER GAS TO ACID GAS REMOVAL	282
14. PREHEATER FLUE GAS	1543
15. VAPOR DISCHARGE	NOT QUANTIFIABLE

Figure 27. Block flow diagram of hydrotreating process (SRC-II Mode)

2.2.6.1 Coal Receiving and Storage

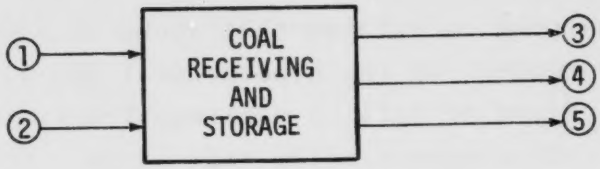
Mine-delivered coal may be received either by rail or truck. It has been calculated that about 29,740 Mg/day of coal would be needed for the hypothetical SRC-II facility. If coal is received by rail, a railroad hopper car dumps each carload into a hopper below rail level. Coal also can be received from mine trucks, where it will also be unloaded into a receiving hopper. A vibratory feeder transfers the coal from the hopper to a belt conveyor, which in turn transfers it to a rail-mounted slewing stacker. The slewing stacker may move along the length of a belt, forming a stockpile on one or both sides of the belt. The stockpile has been designed to hold a three day supply of coal. The stockpiling system will gather up to 1,182 Mg of raw coal per hour. This stockpile does not include the storage capacity of the coal pretreatment operation, since minus 7.6 cm coal (after reclaiming and crushing) is stored there. Coal receiving and storage, as described, is applicable to both the SRC-I and SRC-II modes.

2.2.6.1.1 Input Streams

The only input to coal receiving and storage is delivered coal. Assumed coal characteristics are described in subsection 2.2.2, which describes the coal preparation operation. A block flow diagram is shown in Figure 28.

2.2.6.1.2 Output Streams

Three output streams are associated with coal receiving and storage. Dust is produced during coal handling. Coal pile runoff results from rainfall striking and permeating the coal stockpile. The major output stream, coal from the stockpile, is sent to the coal pretreatment operation.


COAL RECEIVING AND STORAGE
①
②
③
④
⑤

	STREAM	QUANTITY (Mg/day)
1.	DELIVERED COAL	29740
2.	MOISTURE FROM ENVIRONMENT	6.4
3.	COAL TO COAL PRETREATMENT OPERATION	29732
4.	DUST EMISSIONS	8
5.	COAL PILE RUNOFF	6.4

Figure 28. Block flow diagram of coal receiving and storage (SRC-II Mode)

2.2.6.2 Water Supply

A continuous supply of water is needed in the liquefaction operation for makeup water in the cooling towers and for boiler feedwater softening and demineralization operations. It is also needed in the waste disposal treatment facilities and as a general supply of potable, fire, and domestic water. Water usage is dependent upon the size of the plant, housekeeping practices, process operations, and pollution control technologies. A typical raw water treatment process is shown in Figure 29 (6,27). Characteristics of raw water are site specific for illustrative purposes. Illinois's Wabash River is of a capacity sufficient to meet the requirements of SRC plants. In addition it is located near abundant coal reserves. Raw water characteristics for water taken from the Wabash River are given in Table 13.

The following processing procedure applies to both SRC-I and SRC-II systems. Raw water is usually pumped to a treatment plant after being screened to remove large debris. Chemicals are then added to the raw water in a rapid mix chamber as aids in settling out suspended matter and heavy metals in subsequent flocculation, sedimentation, and filtration unit operations. Softening agents are also added in the rapid mix chamber. The water usually drains from the sand filters to a clear well where it is lifted to a raw water storage tank. Water is pumped from the storage tank to the cooling towers and potable water storage area as needed. Chlorination injection facilities are located on the outlet end of the raw water storage tank pumps.

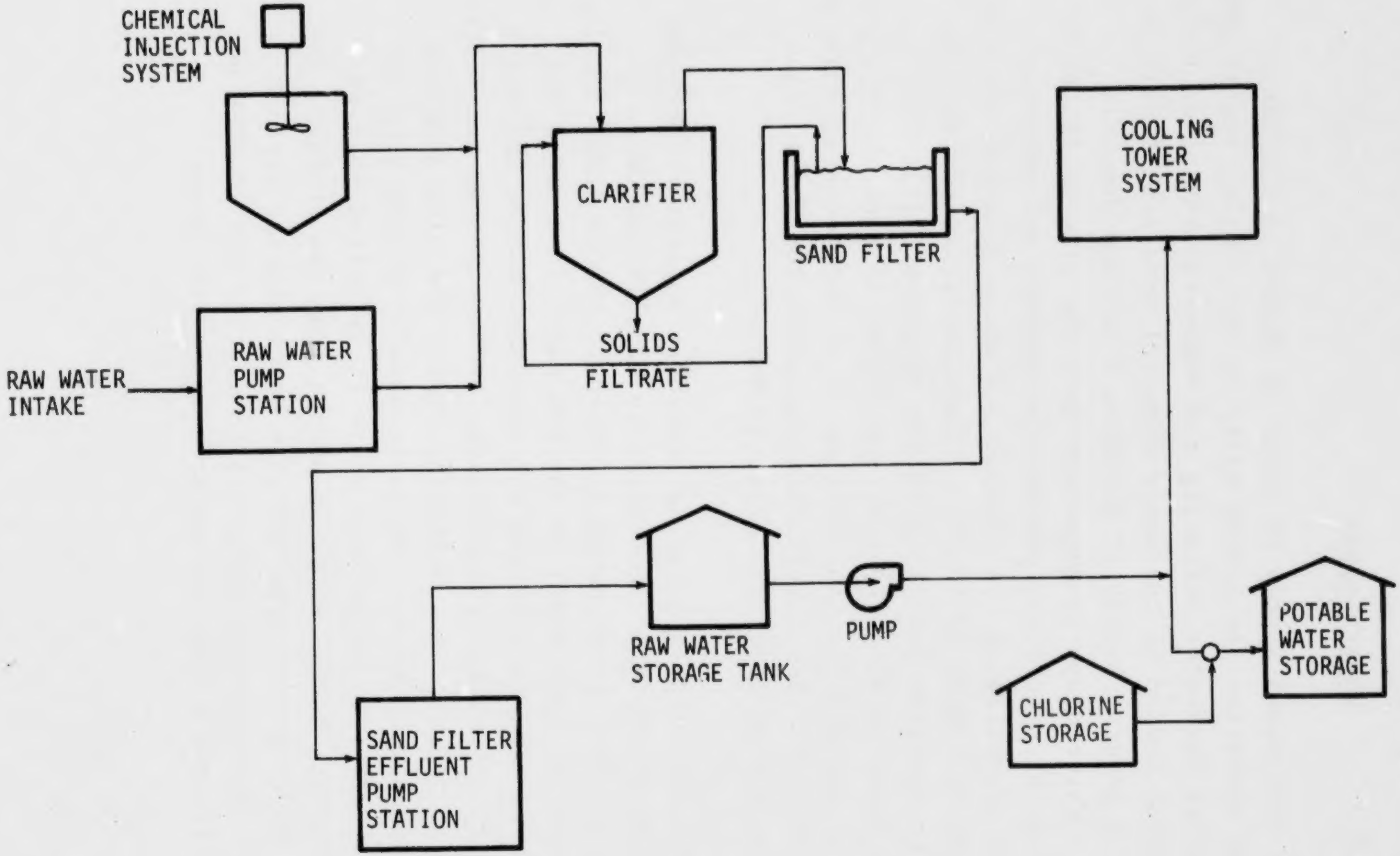

CHEMICAL
INJECTION
SYSTEM
CLARIFIER
SAND FILTER
COOLING
TOWER
SYSTEM
SOLIDS
FILTRATE
RAW WATER
INTAKE
RAW WATER
PUMP
STATION
RAW WATER
STORAGE TANK
PUMP
POTABLE
WATER
STORAGE
CHLORINE
STORAGE
SAND FILTER
EFFLUENT
PUMP
STATION

Figure 29. A typical raw water treatment process

TABLE 13. TYPICAL CONSTITUENTS IN RAW WATER FROM THE WABASH RIVER

Parameter	Range (ppm)	Ave. (ppm)
Specific conductance (umhos)	207-794	535
Temp (°F)	34-86	61
pH (units)	68-74	7.6
Calcium	29-94	66.5
Magnesium	16-32	24
Bicarbonate	110-228	199
Carbonate	0	0
Sulfate	36-180	83
Chloride	8-42	25
Fluoride	0.2-0.4	0.3
Nitrate	0.6-24	12.3
Phosphorous	0.21-1.3	0.75
Dissolved solids (residue at 180°C)	201-508	355
Hardness as $CaCO_3$:		
Calcium, magnesium	134-350	242
Noncarbonate	44-153	97
Detergent (MBAS)	0.0-0.1	0.1
Suspended solids	--	40

2.2.6.2.1 Input Streams

A block flow diagram of the water supply auxiliary process is shown in Figure 30. These are two input streams to the process: raw water and treatment chemicals. The treatment chemicals consist of lime (6.9 Mg/day) and sodium carbonate (7.0 Mg/day).

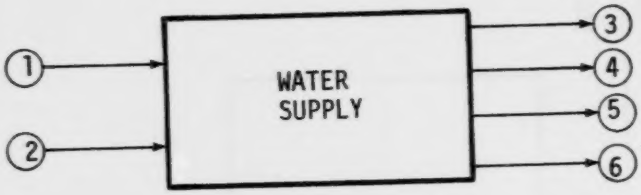
2.2.6.2.2 Output Streams

Output streams from water supply consist of sludges produced during raw water treatment and treated water to various areas of the plant. Water requirements for steam production and water cooling, the two largest consumers of water, have been quantified and reported separately from remaining plant water requirements.

2.2.6.3 Water Cooling

Cooling water, an essential component of a coal liquefaction plant, is needed to cool reactor vessels within the plant and to cool directly various process streams. Cooling towers maintain a continuous supply of cooling water. In addition to the basic cooling tower structure, piping, and other appurtenances, water treatment facilities are also essential components of the cooling tower system since the effective operation of towers can only be maintained by recirculating relatively clean water. A flow diagram of a typical cooling tower system is shown in Figure 31 (6,28).

Cooling water is directed from the cooling tower through closed piping to plant heat exchangers. Before recirculation back to the cooling tower, a portion of the cooling water is directed through a side-stream (blowdown) treatment operation.



STREAM	QUANTITY (Mg/day)
1. RAW WATER	32057
2. WATER TREATMENT CHEMICALS	14
3. SLUDGE (5% SOLIDS)	370
4. WATER TO COOLING TOWER	23092
5. WATER TO STEAM PRODUCTION	3937
6. WATER FOR OTHER PLANT NEEDS	4672

Figure 30. Block flow diagram of water supply

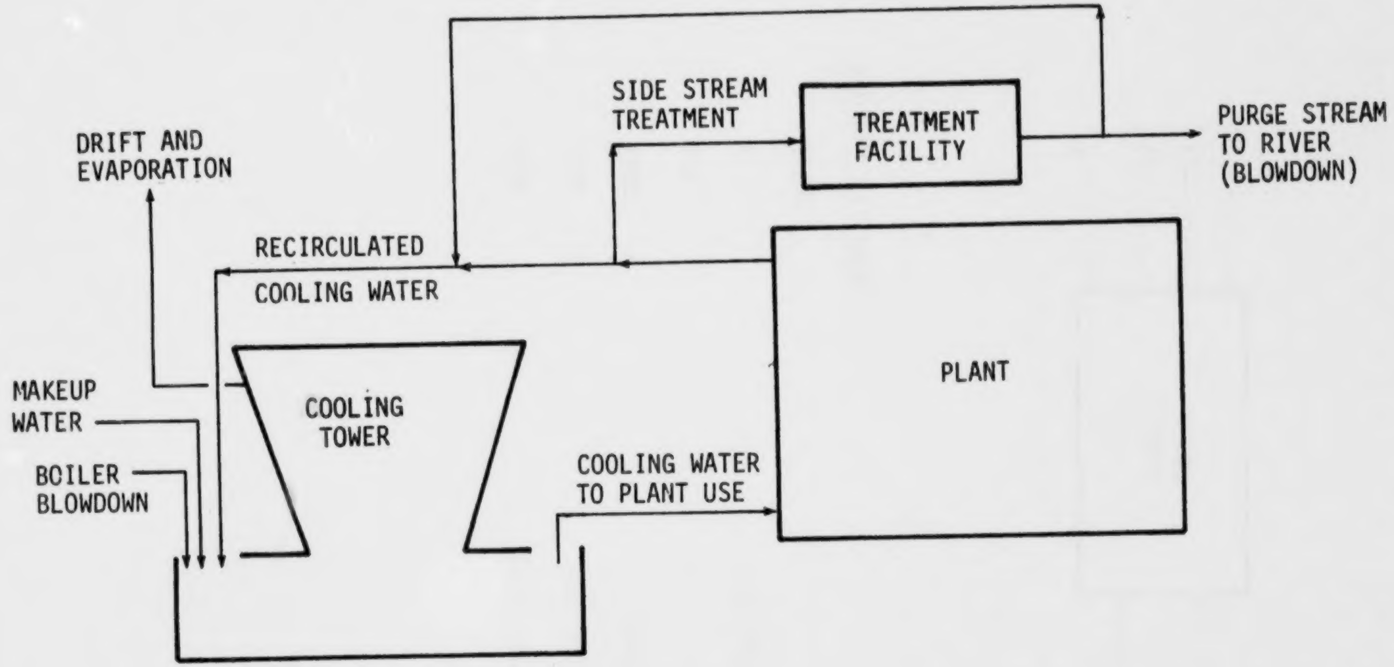

DRIFT AND EVAPORATION
SIDE STREAM TREATMENT
TREATMENT FACILITY
PURGE STREAM TO RIVER (BLOWDOWN)
RECIRCULATED COOLING WATER
MAKEUP WATER
BOILER BLOWDOWN
COOLING TOWER
COOLING WATER TO PLANT USE
PLANT

Figure 31. Typical water cooling process

This is incorporated into the process to maintain a constant level of dissolved solids in the recirculating cooling water stream. With sidestream treatment, typical blowdown rates are 3 to 5 percent of the makeup water rate (6,28). Sidestream treatment facilities used include reverse osmosis, electrodialysis, or ion exchange. The wastewater from the treatment process is generally discharged to the river. Raw water is added to the cooling tower influent as makeup water to replace the water lost by heat dissipation (evaporation) in the cooling towers, by cooling tower blowdown, and by leakage. Evaporation represents the most significant source of cooling water lost in the system.

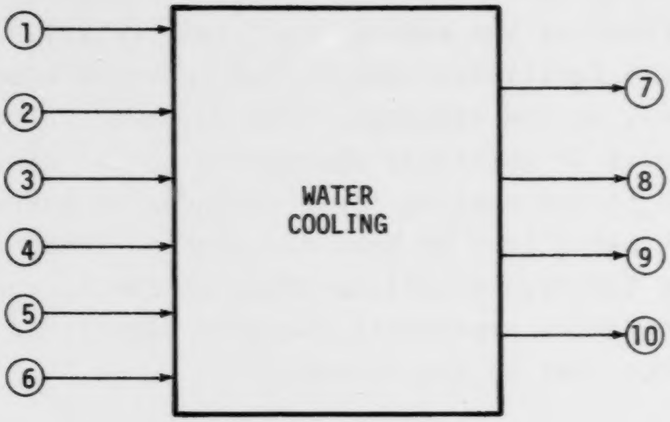
2.2.6.3.1 Input Streams

Makeup water from the water supply process is an input to water cooling. In addition to makeup water, water is returned from system operations, auxiliary processes and treatment facilities comprising SRC systems. Solids produced by scaling during utilization of heat exchange equipment, are present in these streams. More definitive characterization is provided in Section 3.0. Input and output streams associated with water cooling are shown in the block flow diagram, Figure 32.

2.2.6.3.2 Output Streams

There are two environmental discharges resulting from the operation of the cooling towers: drift and evaporation and blowdown. Other output streams are process cooling water and plant water.

Control measures for drift and evaporation from the cooling towers are facilitated only through the design of



STREAM	QUANTITY (Mg/day)
1. MAKEUP WATER FROM WATER SUPPLY	23092
2. BOILER BLOWDOWN	14
3. RECIRCULATED WATER	1145455
4. RECYCLE WATER FROM HYDROGEN GENERATION	245
5. RECYCLE WATER FROM TREATMENT PLANT	4614
6. CHLORINE AND CHROMATES	NOT QUANTIFIED
7. WATER TO PLANT USE	4973
8. DRIFT AND EVAPORATION	22299
9. COOLING TOWER BLOWDOWN	693
10. COOLING WATER	1145455

Figure 32. Block flow diagram of water cooling process

the towers. The concentration of chemicals which may be discharged with the drift may, however, be controlled by varying the rate of blowdown and/or by increasing the degree of raw water treatment. A portion of the circulating cooling water is continuously purged in order to maintain a dissolved solids level of about 50,000 ppm.

2.2.6.4 Steam and Power Generation

Steam and electric power are usually generated on-site in order to make a coal liquefaction plant self-sufficient. There may be times, however, when it is more cost-effective to purchase the required power off-site than to produce it. In this report, it is assumed that power will be purchased. This significantly reduces the on-site coal consumption, cooling water requirements, and gaseous emissions to the environment. It is estimated that about 110 MW are required for the SRC-II facility described (6,13).

The quantity of steam which must be produced on-site is dependent upon the volume of steam produced by various processes and the volume of steam which is consumed.

Steam may be produced indirectly in waste heat boilers located throughout the plant. This reduces the volume of steam which must be produced and provides a means of cooling hot effluents from various unit operations. Usually steam at 4.1 MPa is produced in coal-fired boilers to fulfill the plant steam requirements (6,13).

Most steam produced in the plant is recycled to the boilers in a closed conduit for reuse. In some instances, e.g., hydrogen production, steam may be introduced directly into reactor vessels where it becomes part of the process stream. Makeup water, therefore, must be continuously added to the steam generating facilities.

Typical steam generation facilities are shown in Figure 33 (6,13). Since boiler water must be of high purity, raw makeup water is demineralized prior to entering the boiler water circuit. In order to maintain relatively low concentrations of dissolved solids in the circuit, a blowdown stream also is continuously discharged. This stream is directed to the cooling tower system. Blowdown rates are approximately 0.1 to 1.0 percent of the steam flow (6,29).

2.2.6.4.1 Input Streams

Three materials are required to produce steam: water, fuel, and air. Coal, available in abundance at the SRC facility, is assumed as fuel. Due to water losses during steam utilization, makeup water must be supplied from the water supply process.

2.2.6.4.2 Output Streams

In addition to steam produced to meet system requirements, several other output streams result. The boiler stack gas produced is an air emission which contains particulates and sulfur oxides. Two effluents are produced. The first is the waste produced during demineralization of boiler feedwater. The second is the boiler blowdown withdrawn to maintain desired water purity levels within the boiler. Ash, produced by coal combustion, is a solid waste produced during steam production. Figure 34 is a block flow diagram of the process.

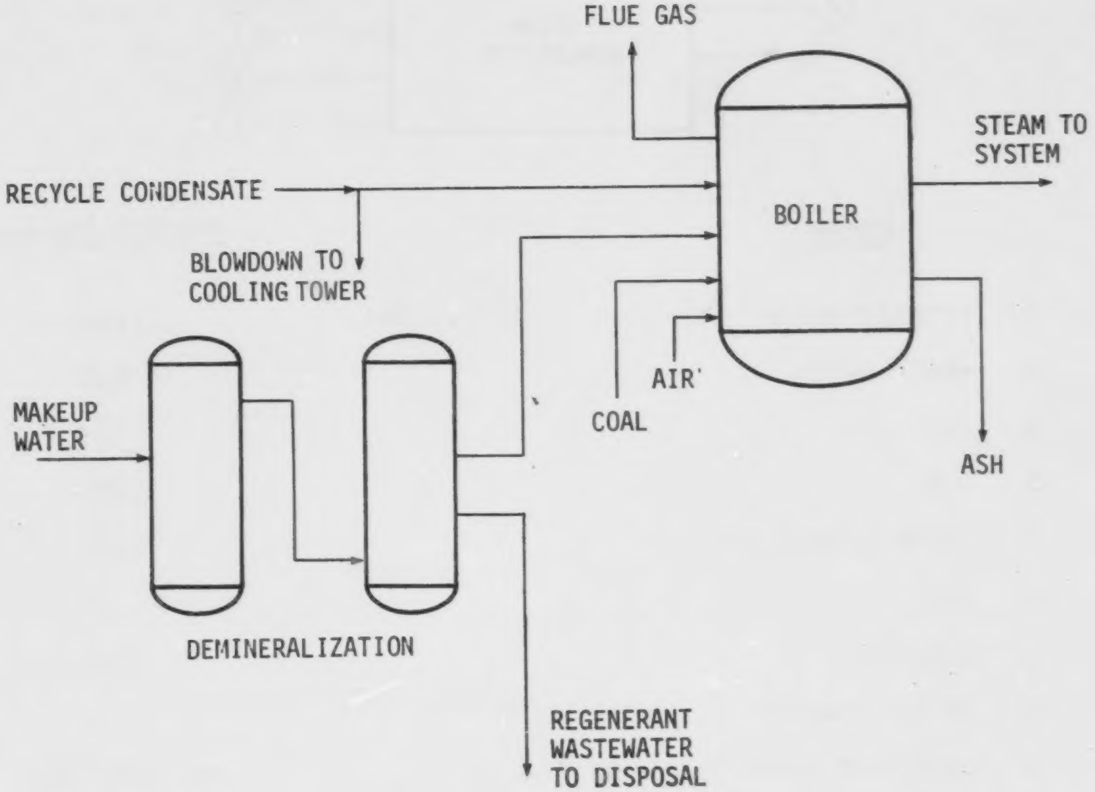
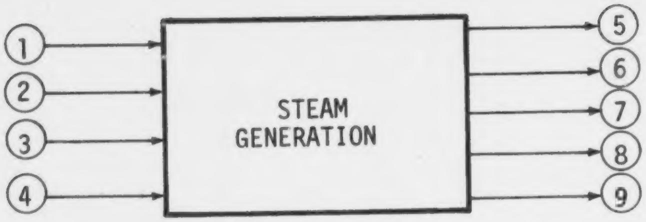

FLUE GAS
STEAM TO SYSTEM
RECYCLE CONDENSATE
BOILER
BLOWDOWN TO COOLING TOWER
AIR
COAL
MAKEUP WATER
ASH
DEMINERALIZATION
REGENERANT WASTEWATER TO DISPOSAL

Figure 33. Steam generation facilities



STREAM		QUANTITY (Mg/day)
1.	RECYCLED WATER	13345
2.	MAKEUP WATER	4677
3.	COAL	929
4.	AIR	11087
5.	STEAM TO PROCESSES	18009
6.	ASH	66
7.	STACK GAS	11950
8.	BOILER BLOWDOWN (TO COOLING TOWER)	14
9.	WASTE FROM DEMINERALIZATION	NOT QUANTIFIED

Figure 34. Block flow diagram of steam generation

2.2.6.5 Hydrogen Generation

Hydrogen is an essential reactant used in SRC systems. In order to produce liquid fuels from coal, it is necessary for the hydrogen/carbon ratio by weight in coal to be on the order of 1:(6-10) (6,25). Since the hydrogen/carbon ratio in unprocessed coal is only about 1:(15-20), hydrogen must be supplied on site either by generation from the gasification of coal, carbon residues, and/or char or by the recovery of hydrogen from gases generated during the liquefaction process (6, 25). This auxiliary process produces hydrogen from coal and coal products. Numerous alternatives are available for producing hydrogen. Figure 35 shows the hydrogen generation unit considered for this design (30).

The four main processing steps employed in the production of hydrogen from coal are gasification, quenching, shift conversion, and hydrogen compression. Numerous pollution control devices are also used to purify the hydrogen gas stream prior to its distribution to liquefaction and hydrotreating operations.

Mineral residue from solids/liquids separation, which contains heavy products, ash, and undissolved coal, is mixed with coal and subsequently introduced into a Koppers-Totzek gasification unit. Oxygen and steam are injected into the coal/residue mixture prior to entering the gasifier. The gasifier operating conditions are 1815° to 1930°C and atmospheric pressure (6,30).

A mixture of hydrogen, carbon monoxide, carbon dioxide, hydrogen sulfide, water, and other trace gases are produced in this process. Approximately 50 percent of the slag also produced in this process is carried along with the product

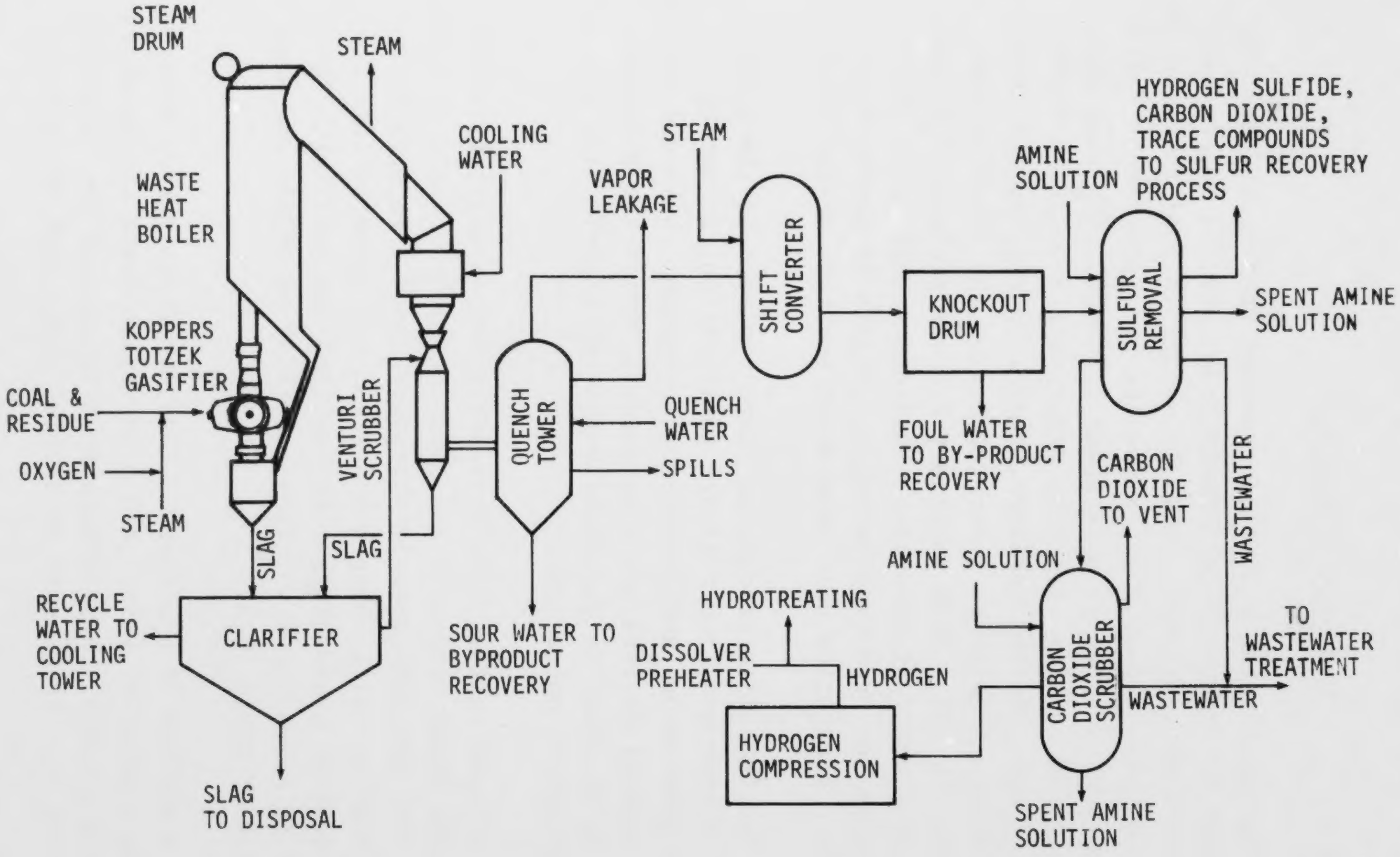

STEAM DRUM
STEAM
WASTE HEAT BOILER
COOLING WATER
KOPPERS TOTZEK GASIFIER
COAL & RESIDUE
OXYGEN
STEAM
SLAG
SLAG
VENTURI SCRUBBER
RECYCLE WATER TO COOLING TOWER
CLARIFIER
SLAG TO DISPOSAL
QUENCH TOWER
VAPOR LEAKAGE
QUENCH WATER
SPILLS
SOUR WATER TO BYPRODUCT RECOVERY
STEAM
SHIFT CONVERTER
KNOCKOUT DRUM
FOUL WATER TO BY-PRODUCT RECOVERY
AMINE SOLUTION
SULFUR REMOVAL
HYDROGEN SULFIDE, CARBON DIOXIDE, TRACE COMPOUNDS TO SULFUR RECOVERY PROCESS
SPENT AMINE SOLUTION
WASTEWATER
CARBON DIOXIDE TO VENT
AMINE SOLUTION
CARBON DIOXIDE SCRUBBER
SPENT AMINE SOLUTION
WASTEWATER
TO WASTEWATER TREATMENT
HYDROTREATING
DISSOLVER PREHEATER
HYDROGEN
HYDROGEN COMPRESSION

Figure 35. Hydrogen generation auxiliary process

gas (6,30). The remainder drops to the bottom of the gasifier where it is water quenched. The slag slurry is then sent to a clarifier where it is concentrated.

Prior to entering a venturi scrubber, the high temperature gasifier product gas produces steam in a waste heat boiler. Cooling water recirculated from the slag clarifier is introduced into the scrubber to remove more than 99 percent of the remaining slag from the product gas (6,30). This slag slurry is then mixed with the slag from the gasifier and concentrated in a clarifier prior to removal to a landfill. The gas is then water quenched to remove impurities such as tar acids, ammonia, hydrogen sulfide, carbon dioxide, and slag. The sour water stream is sent to an ammonia recovery process.

The quench tower effluent process stream is sent to a shifting process where carbon monoxide reacts with steam to produce hydrogen and carbon dioxide. This operation supplements the hydrogen already present in the product gas stream. Temperatures and pressures in the shift reactor are expected to range from 340° to 371°C and 1.0 to 9.7 MPa (6,24). A catalyst is needed in this process. Foul water from the shift reaction is directed to ammonia recovery.

An amine scrubbing unit removes both hydrogen sulfide and carbon dioxide from the clean product gas stream. A subsequent carbon dioxide scrubbing unit removes most of the remaining carbon dioxide. The gases removed from the first unit are sent to sulfur recovery while the carbon dioxide removed from the second scrubbing unit is vented to the atmosphere.

The clean product gas is then compressed and distributed to hydrotreating and liquefaction.

2.2.6.5.1 Input Streams

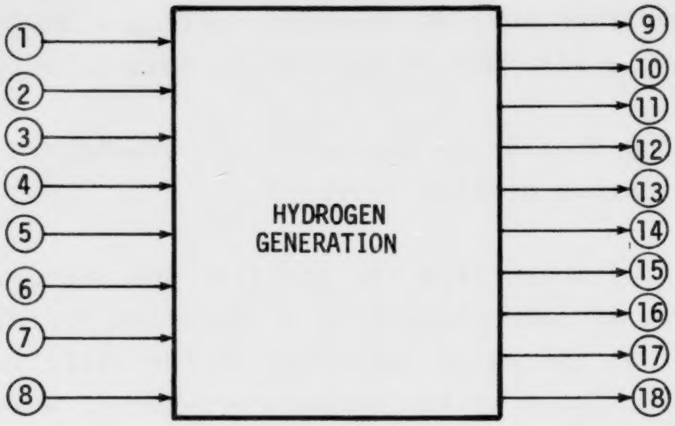
The following input materials are reactants in the hydrogen generation process: oxygen, steam, water and a mixture of coal and residue from solids/liquids separation. Input fuel gas and air are combusted to preheat the reaction mixture to the desired gasifier inlet temperature. Monoethanolamine (MEA) solution is used in the amine scrubber to remove acid gas constituents from the mixture of gases produced in the gasifier. Makeup catalyst is periodically charged to the shift converter to maintain catalyst efficiency. Figure 36 shows a block flow diagram of hydrogen generation with appropriate input and output streams.

2.2.6.5.2 Output Streams

From Figure 36 it can be seen that output streams from the hydrogen production process include waste streams and process streams. Accidental material spills, vapor discharges and spent catalysts are three periodic outputs which may require additional processing or treatment prior to disposal. Output streams discharged on a regular basis include the following:

- Wastewater streams, possibly containing ammonia, tars and oils are continuously discharged from hydrogen generation to wastewater treatment facilities.

- Acid gases (carbon dioxide and sulfur gases, primarily hydrogen sulfide) are discharged from



STREAM	QUANTITY (Mg/day)
1. RESIDUE AND COAL	2753
2. OXYGEN	2551
3. STEAM	4064
4. WATER	671
5. MONOETHANOLAMINE (MEA) SOLUTION	0.9
6. FUEL GAS	52
7. AIR	965
8. MAKEUP CATALYST TO SHIFT CONVERTER	NOT QUANTIFIED
9. SLAG/WATER MIXTURE (60 WT. % SLAG)	1538
10. WASTEWATER	803
11. ACID GAS	5826
12. CARBON DIOXIDE FROM SCRUBBER	684
13. HYDROGEN-RICH PRODUCT GAS	937
14. FLUE GAS	1017
15. WATER TO WATER COOLING	245
16. SPENT CATALYST	NOT QUANTIFIED
17. VAPOR DISCHARGE	NOT QUANTIFIABLE
18. ACCIDENTAL MATERIAL SPILLS	NOT QUANTIFIABLE

Figure 36. Block flow diagram of hydrogen generation process

the amine scrubber to sulfur recovery. Other impurities such as cyanides, nitrogen oxides and ammonia also may be present in this output streams.

- Carbon dioxide is vented to the atmosphere from the carbon dioxide scrubber.
- Slag, removed from the gasifier and venturi scrubbers, is concentrated in a clarifier for disposal. Most of the water recovered in the clarifier is recirculated to the venturi scrubbers, however excess water is returned to the cooling tower.
- Spent MEA solution from the scrubbers is discharged along with the slag.
- Flue gas is discharged as a result of the operation of the gasifier.
- The hydrogen-rich product gas is used as a reactant in liquefaction and hydrotreating.

2.2.6.6 Oxygen Generation

The hydrogen production process used in SRC plants to produce makeup hydrogen for the hydrogenation reactors, may require large quantities of oxygen which must be produced on site. A cryogenic air separation system, consisting of air compression, cooling, and purification, air separation by distillation, and oxygen compression, is normally used to produce the required volume of oxygen. Figure 37 depicts a conventional air separation system (6,31).

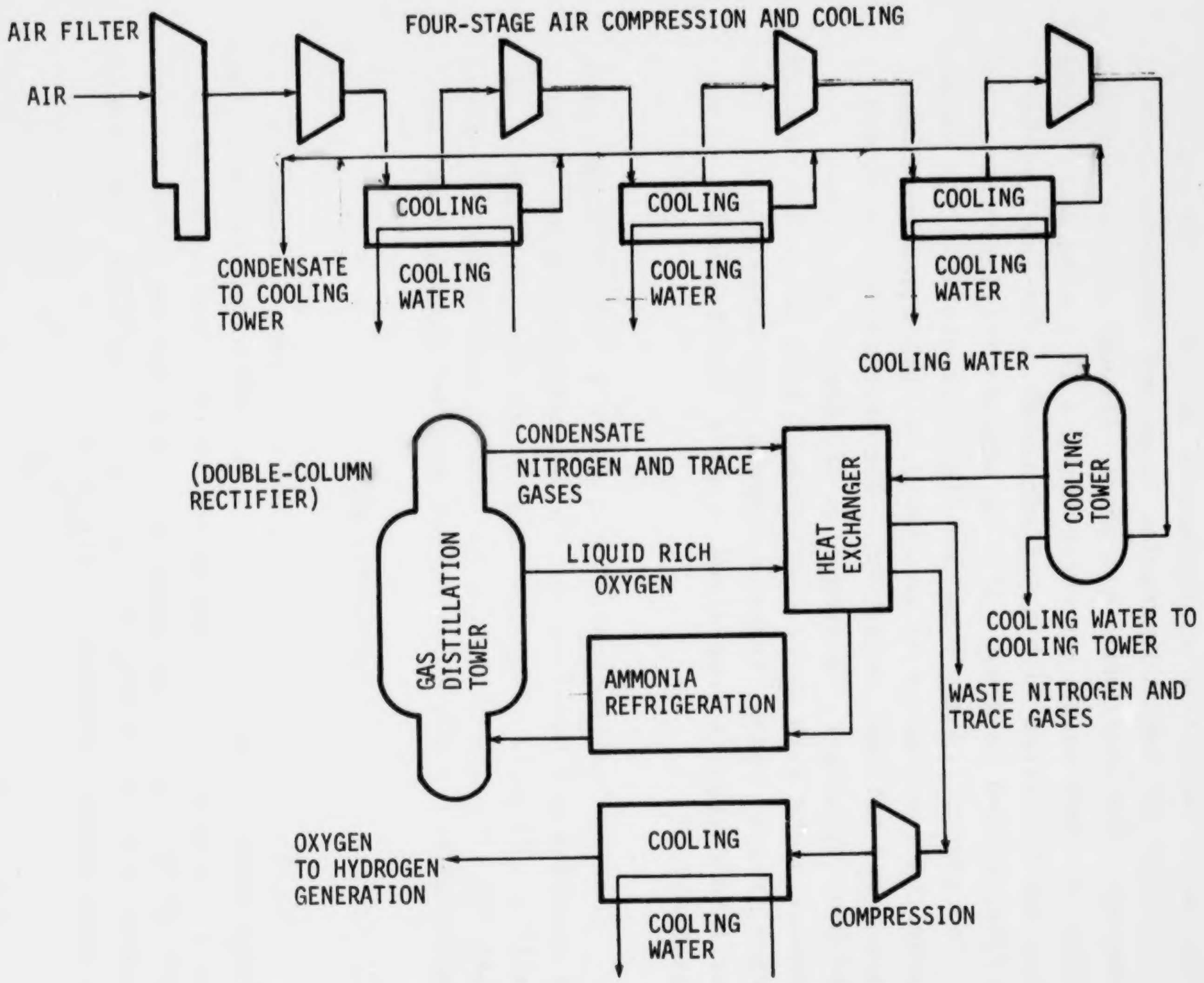

AIR FILTER
AIR
FOUR-STAGE AIR COMPRESSION AND COOLING
COOLING
COOLING
COOLING
CONDENSATE TO COOLING TOWER
COOLING WATER
COOLING WATER
COOLING WATER
COOLING WATER
COOLING TOWER
(DOUBLE-COLUMN RECTIFIER)
CONDENSATE
NITROGEN AND TRACE GASES
LIQUID RICH OXYGEN
HEAT EXCHANGER
GAS DISTILLATION TOWER
AMMONIA REFRIGERATION
COOLING WATER TO COOLING TOWER
WASTE NITROGEN AND TRACE GASES
OXYGEN TO HYDROGEN GENERATION
COOLING
COOLING WATER
COMPRESSION

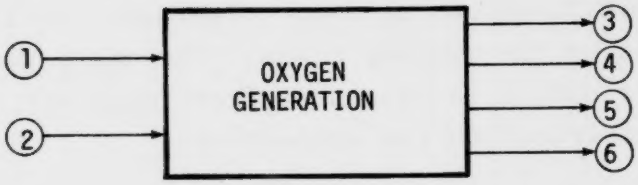
Figure 37. Typical oxygen generation process

In a conventional cryogenic air separation system, air is introduced into a four stage compression chamber which compresses the air to approximately 20.3 MPa. The gas is cooled between each compression stage and condensed water is removed. The compressed gas passes through a water quench tower and heat exchanger where the gas is cooled and contaminants are deposited within the exchanger. The gas is then further cooled to about -30°C by ammonia refrigeration. The cooled gas enters the combined liquefier-distillation chamber where the temperature is decreased to -191°C and the liquid oxygen and nitrogen separated. The products are returned to the heat exchanger. Nitrogen is discharged as a waste product along with trace contaminants such as carbon dioxide, argon, xenon, radon, krypton, oxygen, and water (6,31). The purified oxygen is compressed, cooled, and forwarded to the gasifiers.

Studies have indicated that about 1.5 Mg of oxygen must be provided per Mg of carbon and hydrogen processed in the gasifiers (6,32). Based on this factor and 3,000 Mg/day of coal and residue containing 61 percent carbon and hydrogen, approximately 2,495 Mg of oxygen must be separated per day.

2.2.6.6.1 Input Streams

Air and cooling water are the only input streams to oxygen generation. Air serves as a feedstock from which the desired component (oxygen) is recovered. Cooling water is used in the four stage compression and cooling process to provide initial cooling of input air. The block flow diagram of this process is shown in Figure 38.



STREAM	QUANTITY (Mg/day)
1. AIR (50% HUMIDITY, 15.6^{o}C)	11650
2. COOLING WATER	14913
3. OXYGEN-RICH PRODUCT GAS	2551
4. WASTE NITROGEN STREAM	9088
5. CONDENSATE WATER	11
6. RECYCLED COOLING WATER	14913

Figure 38. Block flow diagram of oxygen generation process

2.2.6.6.2 Output Streams

Four output streams are associated with oxygen generation. The oxygen-rich product gas is utilized in hydrogen generation. Condensed water is produced during initial cooling (dehumidification) of air. After use, cooling water is recirculated to the cooling tower. The waste gases remaining after oxygen is separated from input air (primarily nitrogen) are released to the atmosphere.

2.2.6.7 Acid Gas Removal

The gas separation and the hydrotreating processes generate gases contaminated with hydrogen sulfide, ammonia, carbon dioxide, and small amounts of carbon disulfide and carbonyl sulfide. The substances are formed from the hydrogenation of phenols, aromatic amines, and mercaptans and sulfides naturally present in the parent coal. Reaction of the coal polymer and hydrogen yields these contaminant gases along with more saturated hydrocarbon species (desired product). Most of the contaminated gases also contain significant amounts of unreacted hydrogen and light hydrocarbon fractions. The acid gas removal (gas purification) process removes ammonia, hydrogen sulfide, carbon disulfide, carbon dioxide, and carbonyl sulfide from the gas stream, and leaves a purified gas which can be separated into hydrogen for recycle substitute natural gas, liquid petroleum gas and light oils.

A number of available candidate acid gas removal processes may be employed in SRC plants. The SRC-II system described in this section is based on an earlier report (6) which assumes that the amine-based monoethanolamine (MEA) process is used for acid gas removal. Figure 39 presents a

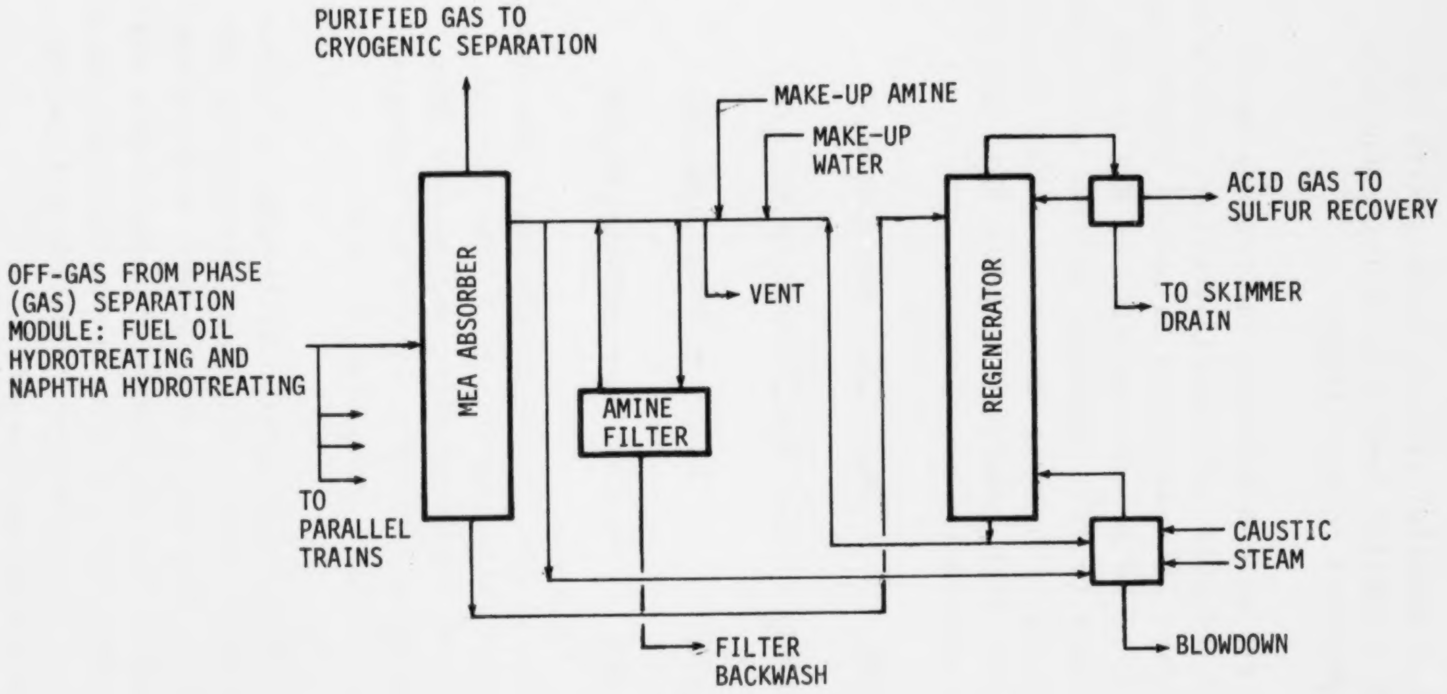

PURIFIED GAS TO CRYOGENIC SEPARATION
MAKE-UP AMINE
MAKE-UP WATER
ACID GAS TO SULFUR RECOVERY
OFF-GAS FROM PHASE (GAS) SEPARATION MODULE: FUEL OIL HYDROTREATING AND NAPHTHA HYDROTREATING
MEA ABSORBER
VENT
REGENERATOR
TO SKIMMER DRAIN
AMINE FILTER
TO PARALLEL TRAINS
CAUSTIC
STEAM
FILTER BACKWASH
BLOWDOWN

Figure 39. Schematic of MEA acid gas removal process

schematic flow diagram of the MEA process. The module consists of a number of parallel process trains, with each train carrying out a similar function. A representative process train is depicted in this figure.

Generally, a gas stream entering the process would first be pumped to the acid gas removal section, consisting of an amine absorber. The gas stream is passed countercurrently through a 15 to 20 percent solution of MEA in the amine absorption tower (6,33). Hydrogen sulfide and carbon dioxide, present along with trace amounts of carbon disulfide and carbonyl sulfide, form complexes with the MEA, described by the following reactions:

(1) $HOCH_2CH_2NH_2 + H_2S \rightleftharpoons HOCH_2CH_2NH_3HS$

(2) $2HOCH_2CH_2NH_2 + CO_2 + H_2O \rightleftharpoons (HOCH_2CH_2NH_3)_2CO_3$

(3) $HOCH_2CH_2NH_2 + CS_2 \rightarrow HOCH_2CH_2NH_2CS_2$

(4) $HOCH_2CH_2NH_2 + COS \rightarrow HOCH_2CH_2NH_2COS$

Only reactions (1) and (2) are reversible. The absorption process is essentially insensitive to the partial pressure of acid gases. Removal efficiencies have been estimated to be approximately 99.6 percent for hydrogen sulfide and 88 percent for carbon dioxide (6,33).

The MEA absorbent is regenerated by thermal decomposition at elevated temperatures. Only hydrogen sulfide and carbon dioxide can be removed in this manner, with carbon disulfide and carbonyl sulfide forming nonregenerable compounds with the amine. Off-gas from the amine regenerator, containing almost all of the hydrogen sulfide and carbon dioxide, is sent to sulfur recovery (6,13).

The nonregenerable organic complexes are removed by a purge stream from the regenerator. Caustic added to the regenerator to precipitate metals also forms nonvolatile salts with the amine complexes, which are discharged as blowdown. Pure MEA is distilled off the regenerator and recycled to the absorption unit (6,13). The purified gas flows into the hydrogen and hydrocarbon recovery process where it is separated into hydrogen for recycle, substitute natural gas, liquefied petroleum gas, and light oils.

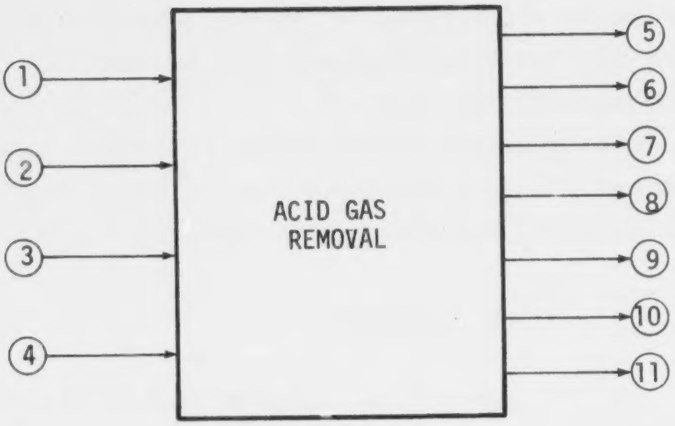
2.2.6.7.1 Input Streams

Figure 40 is the block flow diagram for acid gas removal. Gases produced during gas separation and hydrotreating are combined and charged to the acid gas removal process. Makeup water and MEA are added to maintain MEA solution concentration and absorption efficiency. Caustic, a chemical additive, is used in the amine regenerator. Steam is also input for regeneration of the MEA solution.

2.2.6.7.2 Output Streams

Two process streams are produced as a result of processing the inlet gases. Acid gas constituents are concentrated and sent to a sulfur recovery process. Nonacidic constituents of the inlet gas, or "purified gas" (as shown in Figure 40), are sent to the hydrocarbon/hydrogen recovery process.

Waste streams are also present in acid gas removal. The major wastewater streams are blowdown from the amine generator and ammonia scrubber effluent. An intermittent wastewater stream is backwashed from the amine filter in the acid gas removal unit. Frequency of backwash will depend on



STREAM	QUANTITY (Mg/day)
1. OFF-GASES FROM GAS SEPARATION AND HYDROTREATING	5080
2. MAKEUP WATER TO PROCESS	3
3. ADDITIVES TO PROCESS	0.8
4. STEAM TO AMINE REGENERATOR	NOT QUANTIFIED
5. ACID GASES TO SULFUR RECOVERY	705
6. PURIFIED GASES TO HYDROCARBON/HYDROGEN RECOVERY	4374
7. WASTEWATER (INCLUDES BLOWDOWN AND PURGES)	6
8. FILTER BACKWASH WASTE	NOT QUANTIFIED
9. ACCIDENTAL MATERIAL SPILLS	NOT QUANTIFIABLE
10. FUGITIVE EMISSIONS	NOT QUANTIFIABLE
11. VENTS FROM STORAGE AND SUMP FACILITIES	NOT QUANTIFIED

Figure 40. Block flow diagram of acid gas removal

the flow rate and solids content of the amine stream. Accidental spills will also be a source of intermittent wastewater generation. Fugitive vapor discharges and vents from storage and sump facilities are periodic emissions to air associated with acid gas removal.

2.2.6.8 Sulfur Recovery

Acid gas from the acid gas removal process contains approximately nine percent by volume hydrogen sulfide. It is feasible to convert the hydrogen sulfide gas to elemental sulfur, using the Stretford sulfur recovery auxiliary process.

The Stretford process is applicable to gases with a hydrogen sulfide content no greater than 15 percent. Concentrations as low as 5 to 10 ppm hydrogen sulfide can be achieved for industrial gases, using the Stretford process in combination with the high temperature hydrolysis recovery system (6).

In the process schematic, shown in Figure 41, (6) feed gas from acid gas removal and hydrogen generation passes through a packed absorber where hydrogen sulfide is absorbed in the Stretford solution. The solution consists mainly of sodium metavanadate, sodium anthraquinone disulfonate (ADA), sodium carbonate, and sodium bicarbonate in water. The absorbed hydrogen sulfide is oxidized to elemental sulfur by the reduction of sodium metavanadate. The reduced vanadium compound is in turn oxidized by anthraquinone disulfonate. The ADA is regenerated by air oxidiation in an oxidizer tank. Sulfur floats to the surface as a froth and can be processed by either filtration or centrifugation. Filtrate and wash waters from sulfur separation are returned to the absorption unit.

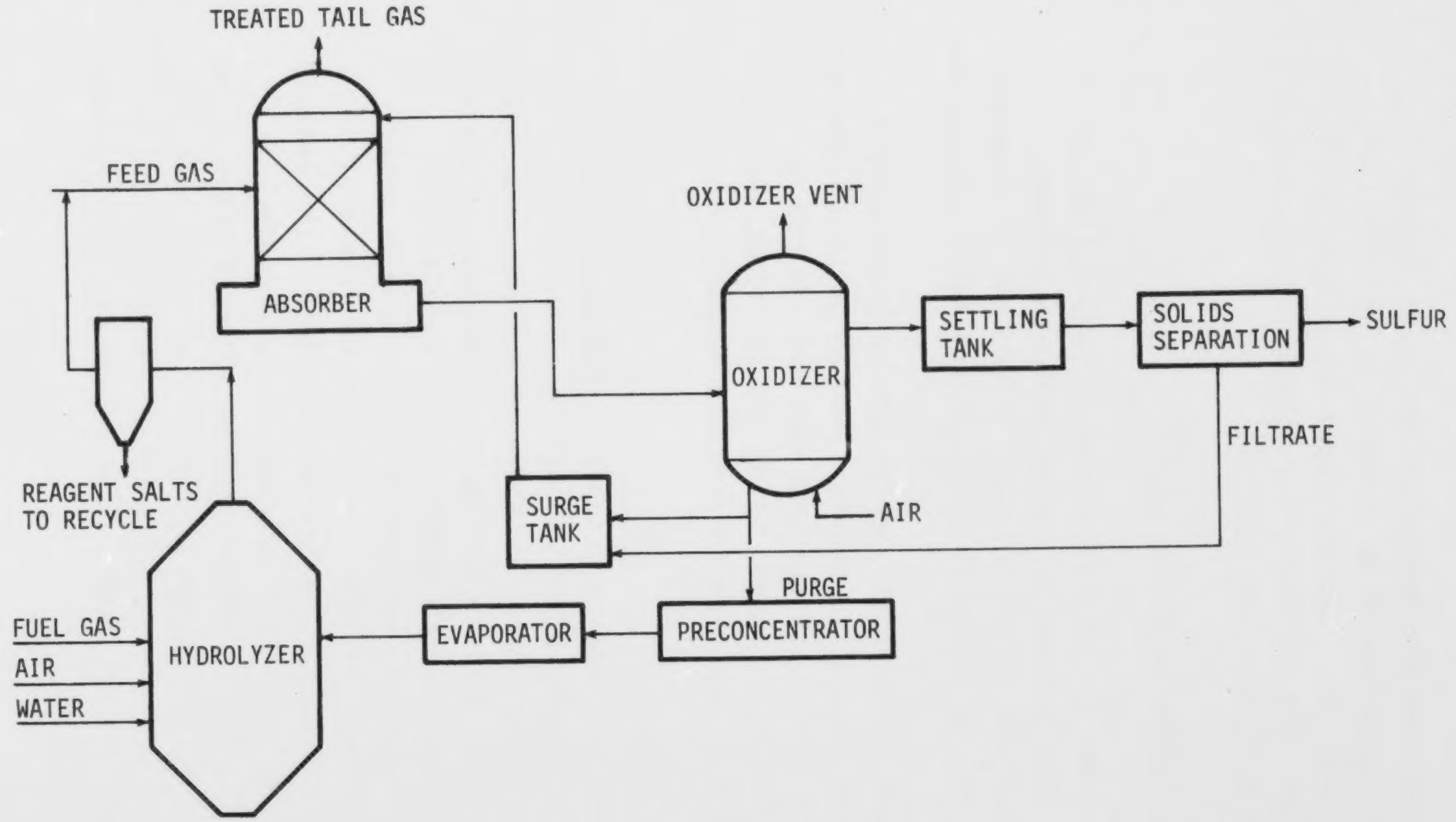

TREATED TAIL GAS
FEED GAS
ABSORBER
OXIDIZER VENT
OXIDIZER
SETTLING TANK
SOLIDS SEPARATION
SULFUR
FILTRATE
AIR
SURGE TANK
PURGE
PRECONCENTRATOR
EVAPORATOR
HYDROLYZER
REAGENT SALTS TO RECYCLE
FUEL GAS
AIR
WATER

Figure 41. Schematic of Stretford sulfur recovery with high temperature hydrolysis

About 400 percent excess air is used to facilitate oxidation and flotation. The overall process reaction is described below (6):

$$H_2S + 1/2\ O_2 \longrightarrow S + H_2O$$

A properly designed Stretford absorber and oxidizing tank will lose about 1 percent of its sulfur production to sodium thiosulfate formation, as shown by the following overall reaction (6).

$$2\ H_2S + 2\ Na_2CO_3 + 2O_2 \longrightarrow Na_2S_2O_3 + 2NaHCO_3 + H_2O$$

Hydrogen cyanide present in the feed gas will be completely converted to sodium thiocyanate in the following manner:

$$HCN + Na_2CO_3 \longrightarrow NaCN + NaHCO_3$$

$$NaCN + NaHS + 1/2\ O_2 \longrightarrow NaCNS + NaOH$$

$$NaHCO_3 + NaOH \longrightarrow Na_2CO_3 + H_2O$$

Sulfur dioxide present in the feed gas will be converted to sodium sulfite in the absorber and oxidized to thiosulfate form in the oxidizer, as follows:

$$2\ Na_2CO_3 + SO_2 + H_2O \longrightarrow Na_2SO_3 + 2\ NaHCO_3$$

$$Na_2SO_3 + H_2S + 1/2\ O_2 \longrightarrow Na_2S_2O_3 + H_2O$$

Continuous purging of the Stretford solution steam prevents the build-up of sodium thiocyanate and sodium thiosulfate to the crystallization point. The purge stream has a total salt content of 20 to 25 percent by weight (6).

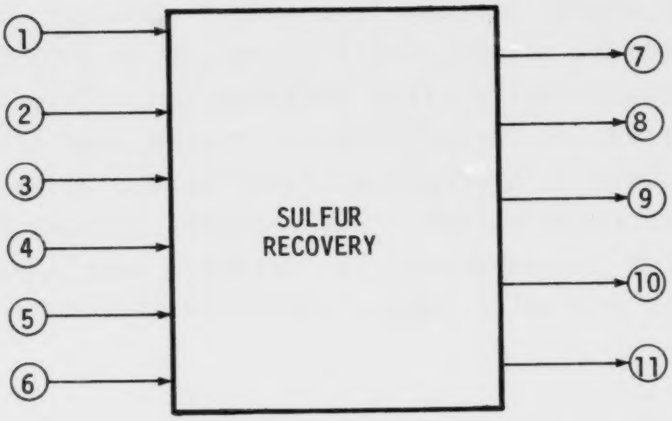
The Stretford solution purge stream is decomposed by a high temperature hydrolysis technique, in which vanadium is recovered in solid form, along with sodium carbonate and some sodium sulfide and sulfate. Hydrogen cyanide is completely converted to carbon dioxide, water, and nitrogen, while sodium thiosulfate is converted to hydrogen sulfide and water.

In the process, the liquid is first concentrated in an evaporator. The concentrated solution is fed to a cocurrent, high temperature hydrolyzer, where the solution is evaporated to dryness and decomposed in a high temperature reducing atmosphere. The reducing atmosphere is produced by the stoichiometric combustion of fuel. Gases leaving the process are cycloned to remove recyclable solids and are fed to the Stretford absorber. The solids containing vanadium and sodium are dissolved and recycled to the Stretford plant.

The nitrogen and water formed during the hydrolysis step are recycled along with the gas stream through the absorber and are eventually vented to the atmosphere in the tail gas.

2.2.6.8.1 Input Streams

Figure 42, the block flow diagram of sulfur recovery, shows six input streams. Two of these, the gases from acid gas removal and hydrogen generation are the feedstock from which sulfur is recovered. Air is used in the oxidizer to convert absorbed hydrogen sulfide to elemental sulfur. Fuel gas, air and water are used in the hydrolyzer which recovers salts used in the Stretford absorber.



	STREAM	QUANTITY (Mg/day)
1.	GAS FROM ACID GAS REMOVAL	705
2.	GAS FROM HYDROGEN GENERATION	5912
3.	WATER	74
4.	AIR FOR OXIDATION	4730
5.	FUEL GAS	8
6.	AIR FOR COMBUSTION	146
7.	EFFLUENT GAS	10979
8.	BY-PRODUCT SULFUR	443
9.	FLUE GAS	154
10.	VAPOR DISCHARGE (OXIDIZER VENT GAS)	NOT QUANTIFIED
11.	ACCIDENTAL MATERIAL SPILLS	NOT QUANFITIABLE

Figure 42. Block flow diagram of sulfur recovery

2.2.6.8.2 Output Streams

The major output streams from sulfur recovery are the recovered elemental sulfur, which is stored as a by-product and the essentially sulfur-free effluent gas. This gas will contain mostly water, carbon dioxide, oxygen, and nitrogen with trace amounts of hydrogen sulfide, carbon monoxide, ammonia, and nitrogen oxides. Other output streams consist of flue gas from the absorber, the oxidizer vent gas, which consists of air and water vapor, and accidental material spills.

2.2.6.9 Hydrocarbon/Hydrogen Recovery

Purified gases entering the hydrocarbon/hydrogen recovery process are cryogenically separated into recycle hydrogen (99 percent pure), substitute natural gas, liquefied petroleum gas, and light oils. A flow diagram of a theoretical cryogenic separation process is shown in Figure 43.

Generally, purified gas from acid gas removal flows to a series of cryogenic separators. The gas stream is first compressed and condensed in a multistage refrigeration unit, then charged to a flash tower. The liquid stream consists of light oils, water, and dissolved ammonia. The liquid stream is charged to a fractionation tower where various hydrocarbon streams are taken off as product. The water and ammonia are removed as a separate side stream and routed to wastewater treatment. The flash gas contains lighter hydrocarbons, hydrogen, nitrogen, carbon dioxide, and carbon monoxide. The flash gas is compressed and condensed in another multistage refrigeration unit and is charged to a de-ethanizer column. Liquefied petroleum gas (propane and butane) is taken off the bottom, while the overhead gases

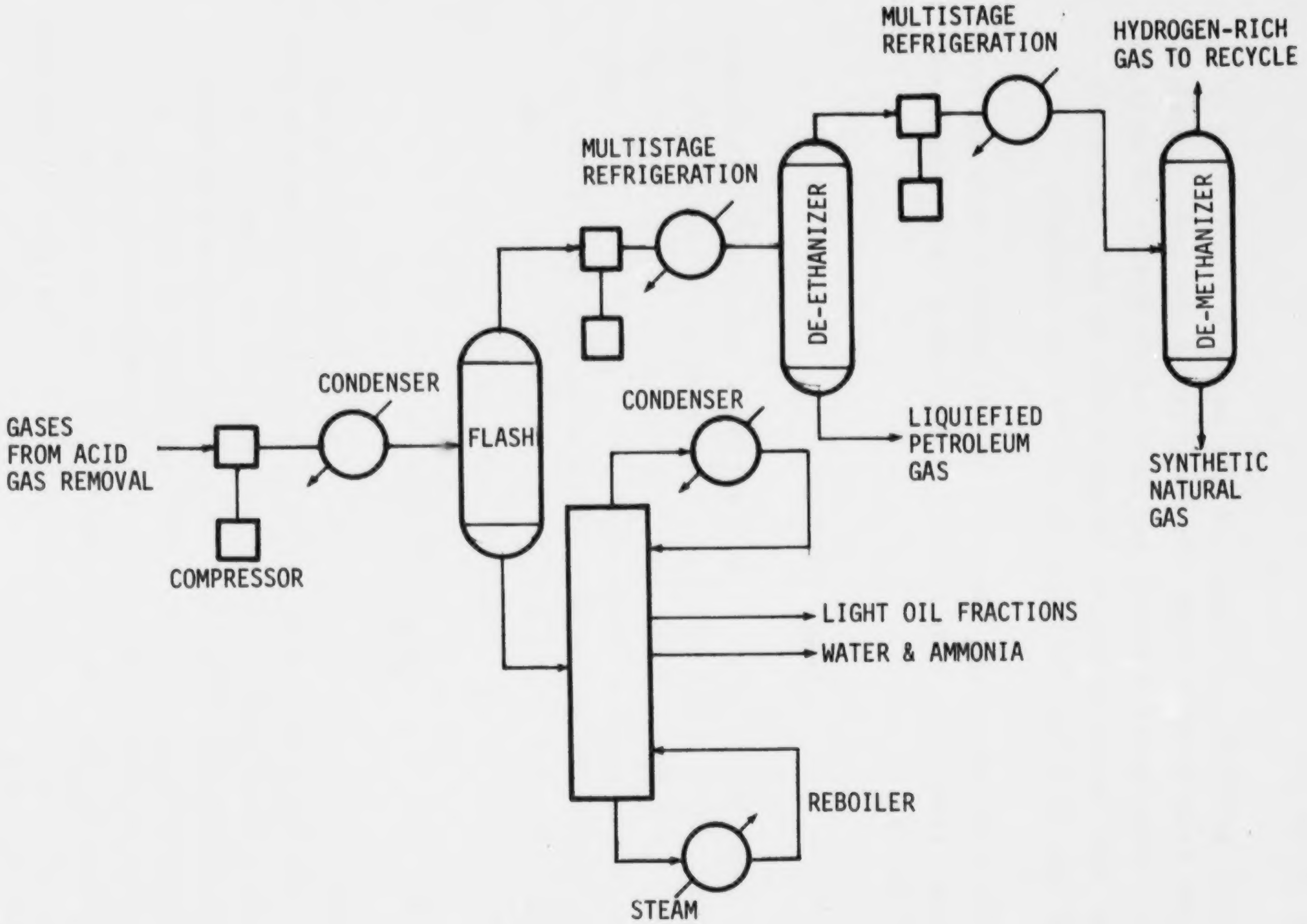

GASES
FROM ACID
GAS REMOVAL
COMPRESSOR
CONDENSER
FLASH
MULTISTAGE
REFRIGERATION
DE-ETHANIZER
MULTISTAGE
REFRIGERATION
HYDROGEN-RICH
GAS TO RECYCLE
DE-METHANIZER
SYNTHETIC
NATURAL
GAS
LIQUIEFIED
PETROLEUM
GAS
CONDENSER
LIGHT OIL FRACTIONS
WATER & AMMONIA
REBOILER
STEAM

Figure 43. Process flow schematic: hydrocarbon/hydrogen recovery

are charged to another refrigeration unit and distillation column (6,26,33).

Pure hydrogen is taken off the top and combined with hydrogen from gasification for recycle to the hydrogenation module. Substitute natural gas consisting mostly of methane, ethane, and carbon monoxide is taken off as the condensed stream and used for fuel gas or is sold as product.

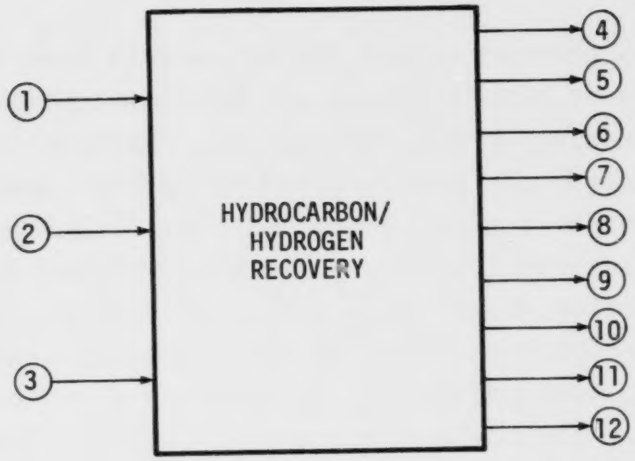
The process scheme above is one of several alternatives for hydrocarbon/hydrogen recovery, depending on the desired end products.

2.2.6.9.1 Input Streams

Figure 44, a block flow diagram of hydrocarbon/hydrogen recovery, shows input and output streams associated with the process. The major input to the process is the effluent gas from acid gas removal which contains significant quantities of molecular hydrogen and volatile hydrocarbons. Process cooling water and steam are used in process heat exchange equipment such as the condensers and reboiler.

2.2.6.9.2 Output Streams

Substitute natural gas (SNG), liquefied petroleum gas (LPG), and light oils are products from hydrocarbon/hydrogen recovery. Recovered hydrogen is recycled to liquefaction and hydrotreating. Condensed steam and used cooling water are recycled to their respective auxiliary processes. A wastewater stream, possibly containing ammonia and phenols, is produced by the fractionator. Other output streams consist of accidental material spills and fugitive discharges from the process equipment.



	STREAM	QUANTITY (Mg/day)
1.	PURIFIED GAS FROM ACID GAS REMOVAL	4374
2.	STEAM	NOT QUANTIFIED
3.	COOLING WATER IN	NOT QUANTIFIED
4.	HYDROGEN	538
5.	SUBSTITUTE NATURAL GAS	2932
6.	LIQUEFIED PETROLEUM GAS	821
7.	LIGHT OILS	52
8.	WASTEWATER	33
9.	CONDENSED STEAM	NOT QUANTIFIED
10.	COOLING WATER OUT	NOT QUANTIFIED
11.	FUGITIVE VAPOR DISCHARGE	NOT QUANTIFIABLE
12.	ACCIDENTAL MATERIAL SPILLS	NOT QUANTIFIABLE

Figure 44. Block flow diagram of hydrocarbon/hydrogen recovery process

2.2.6.10 Ammonia Recovery

Ammonia is present in and may be recoved from wastewaters produced by hydrotreating and hydrocarbon/hydrogen recovery. Depending on the composition, wastewaters from hydrogen production may be processed to recover ammonia, although it was not considered in this particular design (6). The characteristics of wastewaters produced during hydrogen production depend on a number of factors including the gasification process selected and feedstock used (34). Ammonia-bearing wastewaters are directed to a two-stage ammonia recovery stripping tower system (6,35). The process schematic of a typical ammonia recovery process is shown in Figure 45 (6,35).

In order to remove ammonia from the combined wastewater stream, the pH must first be raised to approximately 11.0 by the addition of calcium oxide. The wastewater then passes through a clarifier, to remove any excess lime as sludge, prior to entering the first stripping tower. This sludge is recycled through a lime recovery unit to the lime slaker hopper.

In the first stripping tower, the ammonia wastewater stream flows downward through a packing media where it contacts countercurrently with air. This air stream removes a significant portion of the ammonia from the wastewater.

A second tower is used further to increase the quantity of ammonia recovered from the wastewater. Upwards of 90 percent ammonia removal may be expected with this method (6,35).

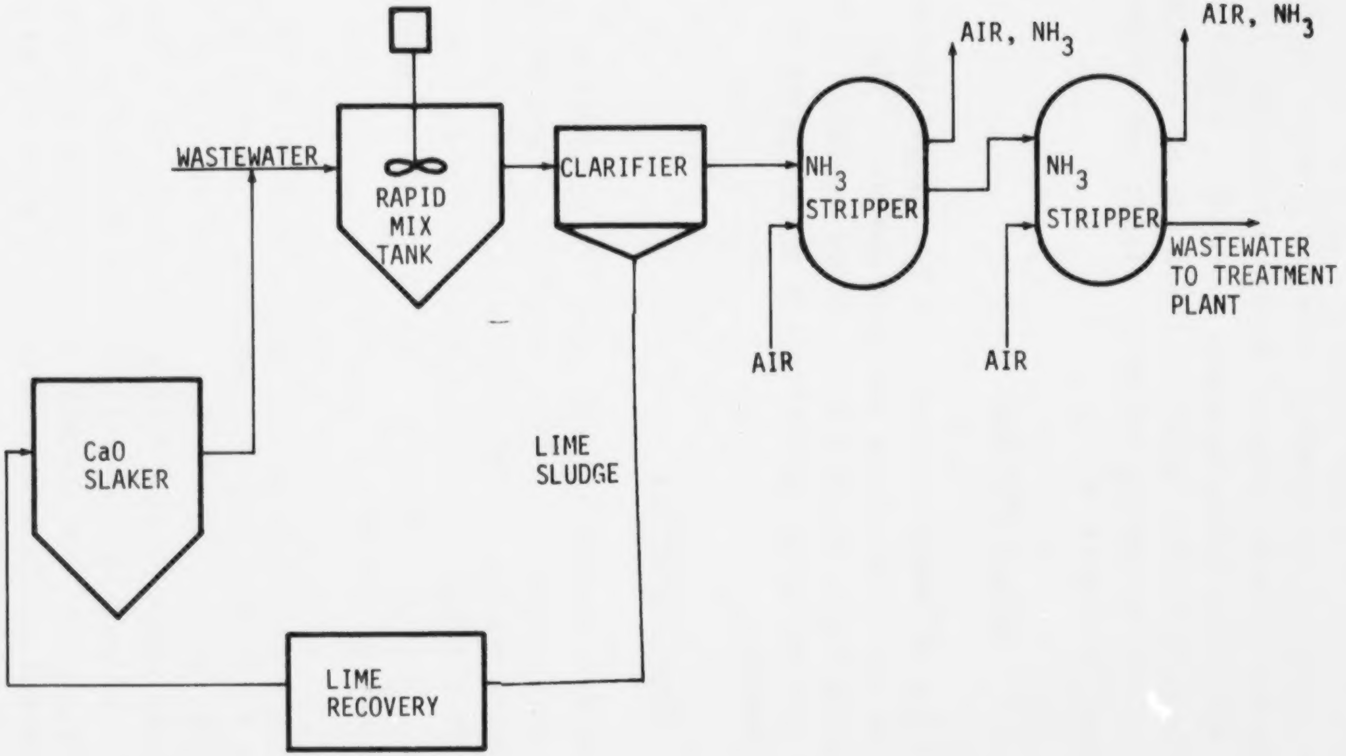

WASTEWATER
RAPID MIX TANK
CLARIFIER
NH$_3$ STRIPPER
AIR, NH$_3$
NH$_3$ STRIPPER
AIR, NH$_3$
WASTEWATER TO TREATMENT PLANT
AIR
AIR
CaO SLAKER
LIME SLUDGE
LIME RECOVERY

Figure 45. Process flow schematic of ammonia recovery

2.2.6.10.1 Input Streams

The major input to the ammonia recovery process is the combined wastewater stream, consisting of wastewaters from hydrotreating and hydrocarbon/hydrogen recovery. Additional inputs are calcium hydroxide solution (used for pH adjustment) and air (used in the stripping columns). Input and output streams are shown in Figure 46.

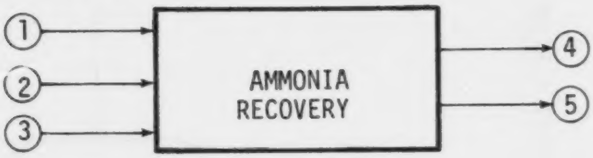
2.2.6.10.2 Output Streams

Air stripping of ammonia results in two output streams. The first is the air, containing stripped ammonia. The second is outgoing water which has a reduced ammonia content and increased calcium oxide concentration and pH level as a result of processing.

2.2.6.11 Phenol Recovery

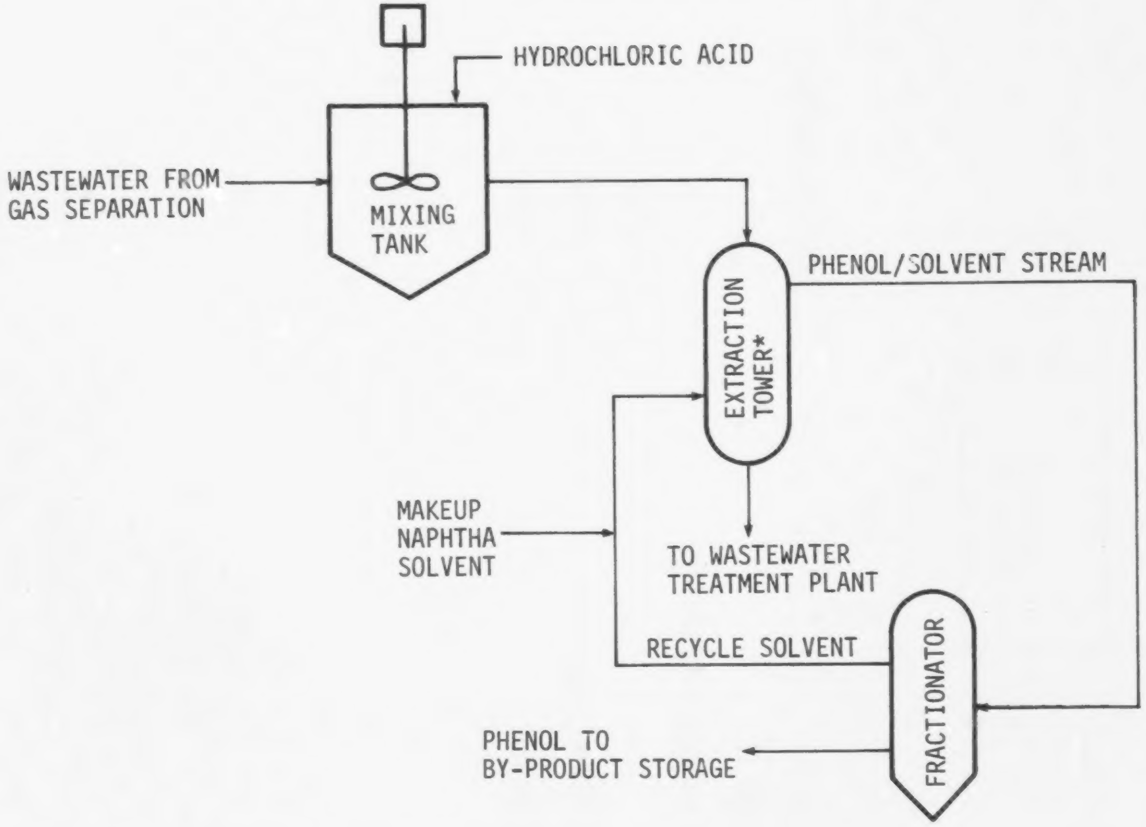
One of the most common methods used for recovering phenol is solvent extraction. It is proposed to use product naphtha to recover phenol in the by-product recovery area. Approximately 99 percent of the phenol is expected to be removed (6,36). A typical phenol recovery auxiliary process is shown in Figure 47 (6,36).

The pH of the phenolic water from gas separation is first adjusted to about 4.0 by the addition of hydrochloric acid. The acidic wastewater is then directed through a series of vessels where it contacts naphtha solvent. The naphtha solvent and wastewater streams pass countercurrently through the vessels so that the most concentrated solvent stream is contacted by the most concentrated phenolic wastewater stream. The amount of phenol which can be removed is


①
②
③
AMMONIA RECOVERY
④
⑤

	STREAM	QUANTITY (Mg/day)
1.	WASTEWATER IN	3932
2.	CALCIUM HYDROXIDE SOLUTION	7
3.	AIR	14786
4.	AMMONIA/AIR MIXTURE	14850
5.	WASTEWATER OUT	3875

Figure 46. Block flow diagram of ammonia recovery process


HYDROCHLORIC ACID
WASTEWATER FROM GAS SEPARATION
MIXING TANK
EXTRACTION TOWER*
PHENOL/SOLVENT STREAM
MAKEUP NAPHTHA SOLVENT
TO WASTEWATER TREATMENT PLANT
RECYCLE SOLVENT
FRACTIONATOR
PHENOL TO BY-PRODUCT STORAGE

*There are a number of towers in series.

Figure 47. Typical solvent extraction phenol recovery process

dependent upon the number of vessels and the ratio of phenol to solvent flow. Economic considerations determine the number of vessels and solvent flow rate to be used. Since detailed economic analyses were not considered in the earlier report (6), it was assumed that the solvent flow rate would be equal to the phenolic wastewater flow rate and that an unspecified number of vessels would be required to remove 99 percent of the phenol. The effluent from the extraction process is directed to the wastewater treatment facilities.

In addition to extracting phenols, the solvent also extracts other hydrocarbons from the wastewater. In the process of extracting hydrocarbons, however, a small portion of the naphtha is partitioned into the wastewater, since it is slightly soluble in water.

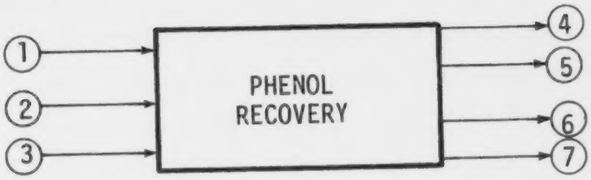
The phenol/solvent stream is sent to a fractionation tower where the phenol is separated from the solvent. The solvent is recycled back to the extraction process, and the phenol is directed to by-product storage.

2.2.6.11.1 Input Streams

Wastewater to phenol recovery is input from the gas separation process. Hydrochloric acid is fed to the process to control the pH of the incoming wastewater. Makeup naphtha solvent is used to replace solvent lost during the extraction process. Figure 48 is the block flow diagram for phenol recovery.

2.2.6.11.2 Output Streams

Recovered phenols are sent to product/by-product storage facilities. The wastewater, now reduced in phenols content and of lower pH is sent to the ammonia recovery process.



STREAM	QUANTITY (Mg/day)
1. WASTEWATER FROM GAS SEPARATION	3135
2. MAKEUP NAPHTHA SOLVENT	3
3. HYDROCHLORIC ACID SOLUTION	31
4. PHENOLS	34
5. WASTEWATER OUT	3104
6. VAPOR DISCHARGE	NOT QUANTIFIABLE
7. MATERIAL SPILLS	NOT QUANTIFIABLE

Figure 48. Block flow diagram of phenol recovery process

2.2.6.12 Product/By-Product Storage

There are a number of products and by-products stored on-site such as liquid petroleum gas, naphtha, SRC fuel oil, sulfur, ammonia and phenols. Pipeline gas is also produced but sent directly into a gas pipeline grid for distribution. Liquefied petroleum gas is normally stored and shipped in atmospheric pressurized tanks. All storage tanks have gas vents which return hydrocarbon vapors to the gas purification area. This system prevents hydrocarbon vapor leakage in the storage area. Solid SRC is stored in open piles or hoppers.

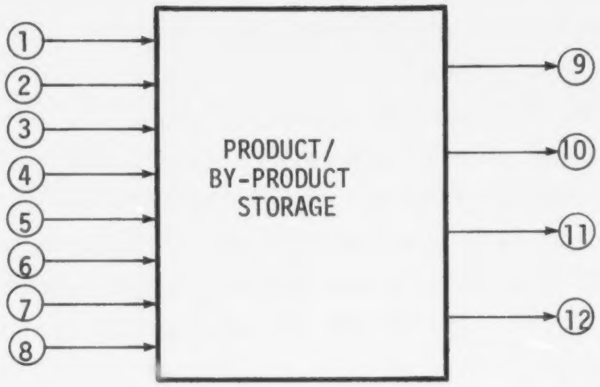
Various by-products such as sulfur, ammonia, and phenols are removed from process waste streams, purified, and also sent to storage. Ammonia and phenols are stored in tanks; sulfur is stored outdoors in piles, or in an enclosed area.

2.2.6.12.1 Input Streams

A block flow diagram of product/by-product storage is shown in Figure 49. It should be noted that the diagram is applicable to the SRC-II system (6). Product inputs consist of liquid SRC, fuel oil, naphtha, SNG and LPG. Sulfur, ammonia and phenols are by-product inputs. If solid-mode SRC-I operation is assumed, solid SRC rather than liquid SRC is input to product/by-product storage facilities.

2.2.6.12.2 Output Streams

No assumptions were made in the previous design (6) regarding product/by-product storage capacity. Consumer demand and selling price will influence the rates at which the various products and by-products of SRC systems are dis-



STREAM		QUANTITY (Mg/day)
1.	LIQUID SRC	5527
2.	FUEL OIL	2591
3.	SUBSTITUTE NATURAL GAS	1312
4.	LIQUEFIED PETROLEUM GAS	821
5.	NAPHTHA	518
6.	SULFUR	443
7.	AMMONIA	64
8.	PHENOL	34
9.	ACCIDENTAL MATERIAL SPILLS	NOT QUANTIFIABLE
10.	FUGITIVE VAPOR DISCHARGES	NOT QUANTIFIABLE
11.	FUGITIVE DUST FROM SULFUR STORAGE PILE	NOT QUANTIFIED
12.	PRODUCTS/BY-PRODUCTS TO DISTRIBUTION	11,310

Figure 49. Block flow diagram of product/by-product storage facilities (SRC-II Mode)

tributed for marketing. Other outputs from product/by-product storage are accidental material spills, fugitive vapor discharges and dust emissions from the sulfur storage pile. For SRC-I systems dust emissions will also result from storage of solid SRC product.

2.3 Process Areas of Current Environmental Concern

This subsection briefly identifies known environmental problems associated with the system operations and auxiliary processes comprising SRC systems. Detailed characterization of the streams cited is performed in Section 3.0. Environmental control technology considerations are made in Section 4.0.

2.3.1 Coal Pretreatment

Numerous waste streams are generated from the coal pretreatment operation. These include coal dust particulate emissions, refuse, coal pile runoff, flue gases from coal dryers, and wastewater produced during coal washing. Despite the number of wastes produced by coal pretreatment, and the fact that waste characteristics can be influenced by many factors, including feed coal characteristics and equipment selection (such as dry cleaning methods as opposed to wet methods), the coal pretreatment operation is not considered an area of major environmental concern. This is because the processes employed in the operation have been used by coal mining and coal-consuming industries for many years and during this time control methods have been developed to minimize environmental problems caused by such wastes.

2.3.2 Coal Liquefaction

Wastes from the liquefaction operation consist of preheater flue gas, the only continuous discharge, and intermittent spills and vapor discharges. Fugitive vapors and accidental spills, although no major threat to the local environment could pose serious problems for workers at the liquefaction plant, because of the possibility of exposure to toxic gases and liquids during attempts to control or abate such discharges. For discharges of this type prevention is as important as control.

2.3.3 Separation

2.3.3.1 Gas Separation Process

As in the coal liquefaction operation, material spills and/or vapor discharges may occur within the gas separation process. Again, problems may exist in the work place but (assuming the accidental spill or vapor discharge is controlled) there should not be any significant effect beyond the SRC system boundary. A sour water stream is discharged from the process. Major components of this water are hydrogen sulfide, ammonia and phenol; however, other organic species are probably present in lesser amounts. Better characterization of these materials and assessments of their toxicities and amenability to control by existing methods must be determined in order to evaluate the relative hazard of this effluent stream.

2.3.3.2 Solids/Liquids Separation Process

The mixture of mineral matter, unreacted coal and liquid organics processed in solids/liquids separation must be given consideration when selecting prevention and control methods for possibly hazardous material spills or vapor discharges. This is true for both SRC-I (which uses filtration) and SRC-II (which uses vacuum distillation) systems. Both systems, although employing different processes to perform solids/ liquids separation, may have a common problem concerning solid waste generation. Depending on the extent to which residues from gasification (in SRC-II) or filter cake (in SRC-I) can be utilized in the hydrogen generation process, significant quantities of these solid wastes could require disposal. Both residues and filter cake need to be studied to determine what treatment measures (if any) should be practiced prior to disposing of these solid wastes.

2.3.4 Purification and Upgrading

2.3.4.1 Fractionation

In many instances fractionation includes an oil/water separator (25) although it is not included in the SRC-II system (6) highlighted in this report. If an oil/water separator is employed in the fractionation it is believed that the wastewater characteristics would be similar to those of the sour water produced in gas separation and that the quantity of wastewater produced would be less than produced by gas separation (11). The possibility of spills or vapor leaks exist in fractionation just as it does in the liquefaction and gas separation operations. Assuming the situation to be controllable, environmental problems should be contained to the work place.

2.3.4.2 Hydrotreating Process

Wastes discharged from the hydrotreating process consist of wastewater, spent catalysts and accidental spills/vapors Existing wastewater treatment technology used for wastewaters generated from hydrotreaters employed in the petroleum industry should, perhaps with minor modifications, minimize environmental concerns regarding this stream. Spent catalysts may either be disposed or regenerated. Disposal seems the most likely option for the carbon residue and spent catalyst withdrawn from the sulfur guard hydrotreating reactor. Minor quantities of spent catalyst are produced. Environmental effects from their disposal should be correspondingly small. As in several of the other system operations, spills and vapor discharges from the hydrotreating operation may intermittently create problems for workers within the liquefaction plant.

2.3.5 Auxiliary Processes

No environmental problems are anticipated for several of the auxiliary processes used in SRC systems because the processes are employed in numerous industrial systems without causing environmental hazards. Such processes include coal receiving and storage, water supply, water cooling, steam and power generation, and oxygen generation. In addition the sulfur, hydrocarbon/hydrogen, ammonia and phenol recovery processes do not directly generate significant waste streams. Instead they process output streams from other processes in the SRC systems to recover useful products and by-products from these streams prior to treatment and disposal. The remaining auxiliary processes, hydrogen generation, acid gas removal and product/by-product storage, produce output streams which could cause environmental concern. These processes are addressed in the remainder of this subsection.

Spills and vapor discharges, while presenting potential localized problems in nearly all operations and processes of SRC systems, are especially dangerous in the product/by-product storage area where, due to quantities of flammable hydrocarbon liquids stored, great care must be exercised to prevent fires or explosions. In addition fugitive dust emissions from storage piles or solid SRC (SRC-I mode) and by-product sulfur must be contended with.

The hydrogen production process is an area of potential environmental concern. Significant quantities of wastewater and solid wastes are generated. The quantity and composition of these waste streams are dependent on both the gasification process and processing scheme selected as well as the gasifier feedstock (coal, filter cake, vacuum residue or mixtures of these materials) (34). Finalization of the hydrogen generation technique and detailed characterization of the wastes produced are required to ascertain the extent of possible environmental problems.

As in hydrogen generation, several process alternatives are available for acid gas removal in SRC systems. Most acid gas removal processes produce a small quantity of wastewater, including a blowdown stream of the solution used for acid gas absorption. Detailed characterization of these discharges (after final designation of the acid gas removal process) is necessary to determine the extent of possible environmental problems.

3.0 CHARACTERIZATION OF INPUT MATERIALS, PRODUCTS, AND WASTE STREAMS

3.1 Summary of Sampling and Analytical Activities

3.1.1 IERL/RTP Environmental Assessment Activities

In July 1978, the EPA/IERL at Research Triangle Park, North Carolina, issued a report setting forth the general guidelines for the development of conceptually sound site-specific environmental assessment sampling and analysis plans (referred to as test plans) for coal gasification plants (37). These guidelines appear to be broadly applicable to Solvent Refined Coal liquefaction system(s), as illustrated in Figure 50.

Within the limits imposed by any of the predetermined test plan objectives, the performance of an engineering analysis is a basic requirement in the development of the sampling and analytical strategies. Another important aspect of an environmental test plan is referred to as data management, encompassing the following areas (37):

- Planning and statistical design of experiments
- Data validation
- Data evaluation, and
- Data handling.

The various types of source tests and descriptions of test objectives are as follows (37):

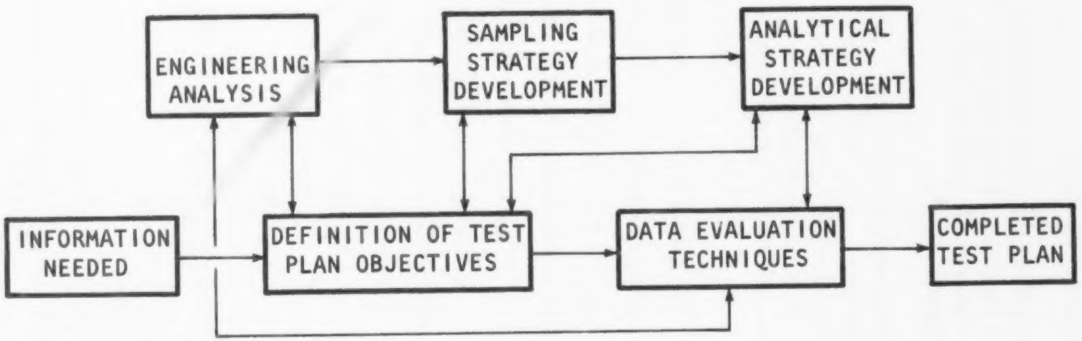

ENGINEERING ANALYSIS
SAMPLING STRATEGY DEVELOPMENT
ANALYTICAL STRATEGY DEVELOPMENT
INFORMATION NEEDED
DEFINITION OF TEST PLAN OBJECTIVES
DATA EVALUATION TECHNIQUES
COMPLETED TEST PLAN

Figure 50. Interrelationships among general areas involved in preparing an environmental test plan (37)

Test Type	General Statement of Test Objectives
Waste stream characterization	To identify and quantify the pollutants found in a facility's multimedia (gaseous, liquid, and solid) waste streams and to evaluate their health and ecological effects.
Control equipment characterization	To determine the effectiveness of existing or developing control equipment for removing pollutants from waste streams.
Process stream characterization	To determine the origins and fates of pollutants as they pass through selected processes and to evaluate the effects that process operating parameters have on pollutant types and concentrations.

These source tests may be conducted during one or more of the following process or plant operating conditions: (1) normal operation; (2) start-up; (3) shutdown, and (4) emergency upsets (37). With regard to the waste stream characterization test, the EPA has established guidelines for Levels 1 to 3, and multimedia environmental goals for the evaluation of health and ecological effects or hazards from toxic substances (38,39,40). For a detailed discussion of the several key areas shown in Figure 50, the reader should consult Reference 37, page et al. (1978).

3.1.1.1 Level 1 Assessments of SRC-II by Hittman Associates, Inc.

In March 1978, Hittman Associates, Inc., conducted a partial Level 1 environmental assessment of the SRC-II pilot plant at Fort Lewis, Washington (41). In this initial assessment, grab sampling was performed only on certain liquid/slurry streams and solids streams of some main unit operations (e.g., SRC products and by-products), and on certain streams of the wastewater treatment system. The rationale for sampling and analysis of the wastewater treatment process was to obtain an estimate of the efficiencies of the various treatment units (e.g., the flottazur efficiency) in lowering the concentrations of organic and inorganic pollutants contained in the multimedia waste streams discharged from specific treatment units. Such information could be useful in the final design of a wastewater treatment plant for a commercial SRC system. The sampling points designated for this particular source test are given elsewhere (41).

Grab sampling was also performed on the SRC liquid product and the naphtha and middle distillate streams from the fractionation unit, and the residue from the heavy bottoms stream from the solids/liquids separation process. During the grab sampling effort, the feed coal used in the SRC-II pilot system was Illinois No. 6 coal, containing about four percent sulfur, 14 percent ash and 18 percent moisture, as received. Moisture-free coal was fed to the liquefaction unit at a rate of 27,194 kg per day. Coal dissolution was carried out at an average temperature of 454.9°C and a pressure of 13.3 MPa (41). The reader is advised that data from pilot plant facilities cannot be translated directly into a standard-size (28,000 Mg of feedcoal per day) commercial SRC system, without further testing under demonstration plant conditions.

The results obtained on the effectiveness of the several treatment units in removing organic and inorganic pollutants were assessed, keeping in mind the factors that differentiate between the SRC pilot plant and a commercial system, as follows (41):

- The wastewater feed from the SRC-II pilot plant to the waste disposal treater is considered to be diluted from 5 to 8 times more than that of a commercial SRC system estimated to use about 32,000 Mg of water per day.

- The rate of production of the process related wastewater in the SRC-II pilot plant amounted to only about one percent of the total feed to the wastewater treater system, compared to about 25 percent for a commercial SRC system.

- Phenols were not stripped from the SRC pilot plant wastewater, as will probably be done in a commercial SRC system.

- The sole point source effluent discharge from the SRC-II pilot plant is reported to be the filter backwash tank effluent.

Within the constraints imposed by the above factors, the following observations appear pertinent:

- Results from the infrared analyses of the biounit streams suggested that the following classes of hydrocarbons remain in wastewater following biological treatment but below the Washington State effluent requirements (41):
    - aromatics, including substituted benzenes, naphthalenes, and other polynuclear hydrocarbons.

  - compound classes with carbon-oxygen single and double bond stretches representing aldehydes, acids, and esters.

  - aliphatic hydrocarbons, or alipathic substitution on ring compounds.

  - compounds with carbon-nitrogen double bond stretches including amines.

  - phenols.

- The C_8-C_{16} hydrocarbons were concentrated in the flottazur skimmings.

- The biounit treatment removed 99 percent of the C_8-C_{16} hydrocarbons remaining in the flow from flottazur through the biounit.

- The carbon filter unit (the last in the wastewater treatment unit chain) proved effective in removing certain organics which were refractory to biological treatment.

- The net reduction of dissolved solids by the treatment system amounted to approximately 14 percent; this finding is relevant in that the majority of the trace elements were found to occur as dissolved solids rather than suspended solids. The data from spark source analysis of the wastewater streams suggested that calcium, sulfur, vanadium, and fluorine exhibited poor removal efficiencies; the relatively high concentrations of sulfur and vanadium may warrant serious attention in the final treatment design.

- Based on the high removal efficiency of the treatment system for heavy metals, it appears that these elements (e.g., Sb, Sn, and Ti) are largely present on the suspended solids.

- The source of the high concentrations of polynuclear aromatic hydrocarbons found in the feed to the wastewater treatment system undoubtedly arose from leaks in the washdown of process areas and accidental discharges. Such leaks and spills would likely be minimized in a commercial SRC system (41).

3.1.1.2 Studies on Leachates from SRC Liquefaction Residues by the Illinois State Geological Survey (42)

Leachates from the SRC liquefaction dry mineral residue (from Kentucky No. 9 coal) were analyzed for 43 soluble constituents using atomic absorption and colorimetric techniques. Soluble constituents in the SRC mineral residue were measured in leachates (10 percent slurries), under conditions of chemical equilibrium in the laboratory (e.g., from 3 to 6 months time) on duplicate sets of slurries over the pH range from 2.9 to 10.2. Soluble constituents in SRC leachate whose equilibrium concentration in the aqueous phase exceeded recommended water quality levels were: boron, calcium, ammonium (NH_4^+) and sulfate (42).

In studies of the capacity of three different Illinois soil types to attenuate the behavior of chemical constituents in leachates from SRC liquefaction solid wastes, the results indicated that the degree of removal from leachates of the pollutants Fe, Zn, and B varied directly with the cation exchange capacity (CEC) of the soil clay and organic colloidal fractions. From this investigation, the cation magnesium was found to present the greatest problem as a possible pollutant from land disposal in two of the three soil types, referred to as the Catlin silt loam and Ava silty clay loam. For example, it was found that the concentration of Mg in the original leachate, compared to that in the filtrate (after elution from soil columns) showed a 20-fold increase; this cation-exchange reaction has been found sufficient to cause increases in the hardness of ground waters around waste disposal sites with these soils (42).

3.1.1.3 Site-Specific Evaluation of the Conceptualized SRC-II System by Hittman Associates, Inc. (43)

An effort was made to estimate the potentially adverse effects of major pollutant stressors predicted to emanate from a hypothetical, standard-sized SRC-II system presumed to be located and operated along the Wabash River in White County, Illinois (43). The Standards of Practice Manual for the SRC Coal Liquefaction Process (6), prepared earlier by Hittman Associates, served as the conceptualized basis for said effort. The White County study includes updated information on the identity and levels of emissions, effluents, and solid wastes associated with the construction and operation of an SRC-II system, conceptually using about 28,000 Mg Illinois No. 6 coal per day. In addition, updated information on the existing regulatory requirements applicable to the SRC-II system, and on the Multimedia Environmental Goals (MEGs) and the Source Analysis Methodology (SAM) concepts was used to evaluate the environmental goals and apparent safe limits for the various pollutants resulting from the operation of the White County SRC-II facility (43).

Finally, a detailed description was made of the total White County environment, as it presently exists, without the proposed SRC-II system. Generic and site-specific environmental issues and constraints were identified. A detailed discussion was also made of the influence of known environmental dissipative, and/or exacerbative forces (physical, chemical, and biological) that may act to decrease, increase, or sometimes neutralize the adverse effects of pollutants. For example, the chemical form of a pollutant in combination with other pollutants appears determinant to pollutant action via absorption, metabolism, excretion, and bioaccumulation (43).

The highlights of this site-specific evaluation with respect to the expected pollutant discharges are reported as follows (43):

- Emissions to the atmosphere during the operation of the SRC-II system are expected to arise primarily from the auxiliary processes; these discharges include flue gases and fugitive emissions from coal pretreatment and the dryer stack gas. Emissions from the main unit operations of the SRC system are (mostly) expected to come from leaks in pump seals, joints and flanges, and from product/by-product handling and storage activities; these emissions should be monitored in the workplace on a regular basis since present evidence suggests the likely presence of hydrocarbons, toxic aromatics, and metal carbonyls.

  Trace elements present in fugitive emissions (i.e., dusts) from the coal pretreatment area include aluminum, chromium, and nickel among others. Present evidence suggests that the fugitive particulates escaping from treated stack gases are enriched in copper, molybdenum, selenium, zinc and zirconium. Unquantified amounts of polynuclear aromatic hydrocarbons (PAH) were reported to be associated with the particulates that escape air pollution control equipment. Carbon dioxide emanations from the SRC-II system were reported to be about 20,000 Mg/day.

- Insofar as the SRC process wastewaters will be treated and recycled and not discharged, there appears to be nominal concern for any untoward effects from cyanides, phenols, sulfides, and ammonia. This is not true for the dissolved solids (TDS) in wastewater streams with TDS levels ranging up to 44,000 mg/liter. Effluent discharges from the main unit operations of the SRC system are expected to arise primarily from emergency shutdown, cleanup and startup, and from accidental spills during the handling of the process and product aqueous streams. Until full scale demonstration plant tests are completed, however, the actual degree of hazard from PAHs, trace elements, and other toxic substances cannot be established for these discharges.

  The SRC process wastewaters reportedly contribute essentially all of the organic polluants generated in the system; however, the precise identity and level of toxic organics in wastewaters cannot be fully assessed until the demonstration plant(s) are in operation.

- One of the largest categories of solid waste to be disposed of from the SRC-II system (excluding the coal pretreatment operation) is the hydrogen production slag (40 percent water), at 1538 Mg/day. This solid waste will, like the coal operation wastes, be sent to disposal at the mine site. In the biological treatment unit sludge (discharged at about 0.5 Mg/day) the mercury and nickel levels may present a potential health hazard.

The 11,368 Mg/day of liquid SRC product, and the naphtha and middle distillate by-products reportedly contain appreciable levels of naphthalenes, alkyl benzenes, phenanthrenes and other aromatics in the 343°-511°C fraction. The effect of the several process variables (e.g., pressure, temperature, and time) on the distribution of these suspected hazardous substances is poorly understood and requires resolution in a large-scale SRC-II demonstration system (43).

3.1.1.4 Estimation of the Average and the Maximum Composition of Process and Waste Streams by Hittman Associates, Inc. (44)

In the present state-of-the-art, estimates of pollutant levels in SRC process and waste streams are sometimes based on one sample of coal of unreported composition. In developing a technique for predicting the pollutant composition of process and waste streams of a conceptualized SRC system, there is some merit in establishing sets of values for U.S. coals, referred to as the "average" and the "maximum" elemental composition of U.S. coals. These values may be used, in turn, to predict the average and the maximum possible pollutant concentration (usually for the inorganics) in various process and waste streams of the system, provided that one derives a set of partitioning factors for the various pollutants in the several streams of interest.

The average and the maximal average composition of U.S. coals (largely bituminous) was estimated simply by treating the published average and maximal values for the constituents as if they were raw data (44). Partitioning factors were next derived by using the data of Filby et al. (45), and of Dailey, et al. (46), whereupon sets of partitioning factors (F), where:

$$F = \frac{P_{x(\text{ps or ws})}}{Px_{\text{ coal feed}}}$$

where (p_x) is the average or maximal concentration of the pollutant (x) is either a process stream (ps), or a waste stream (ws), and p_x in the average or maximal concentration of the same inorganic element (x) found in the feed coal. Thus, the partitioning factors are based on actual analyses of the process or waste streams; it is assumed that these factors have equal rank with any other actual stream analysis, since these factors allow the data to be generalized to any feed coal. Hence, once the composition of a given feed coal is known, one may estimate the composition of the product, process, and waste streams (44).

Implicit in these derivations are several other assumptions as follows: (1) that the concentration of the pollutant in a given stream is rather more affected by the feed coal composition than by the usual variations in SRC-II process parameters, and (2) that every constituent in every particle of coal in the United States acts similarly to those constituents in every other particle of coal in the United States. These assumptions neglect any matrix effects and other unidentified interactions (44). Results obtained by use of this concept for multimedia waste streams of the conceptualized SRC-II system are presented in Sections 3.5 to 3.7.

3.1.1.5 Radionuclides in Feed Coal and SRC Samples (47)

Hittman Associates, Inc., conducted analytical studies of the levels of major radionuclides and their potential health hazard in Kentucky and Illinois bituminous coals, and in the SRC-I product, SRC fly ash, and Kentucky coal fly ash obtained from a combustion test at the Georgia Power Company's Plant Mitchell during May and June 1977. Two sets of samples were analyzed for radionuclides in the Georgia Power system, taken from the 10-micron, 3-micron, and 1-micron cyclones, and from the filters of Kentucky Coal Run No. 1 and SRC Run No. 2 (47). Theoretical analyses were also carried out on the Illinois No. 6 feed coal required to operate the conceptualized SRC-II system discussed in previous reports (43,6).

Results obtained from these studies strongly supports the view that thorium and its daughter products occur mainly in the SRC bottom ash and the SRC particulates (i.e., the collected fly ash). However, the levels of thorium, uranium, and their daughter products that may be discharged from an operational, standard-size SRC system (as dusts and bottom ash from 28,123 Mg/day of Illinois No. 6 coal) were about 290 mCi (43).

With regard to the degree of radiological exposure of a worker breathing 350 grams of coal dust (Illinois No. 6

coal) containing 290 mCi of radioactivity, and considering the total number of radionuclide disintegrations, the energy of each disintegration, and the relative biological effectiveness of each disintegration, the conclusion was reached that the cumulative exposure of a worker during the 30-year lifetime of a commercial SRC facility (260 days worked per year) would be 3.5×10^{-9} rad or 3.0×10^{-8} rem. This exposure level was found to be well below the maximum permissible rem for a worker breathing 350 grams of coal dust per year. However, since it is generally accepted that at least 90 percent of the uranium and its daughters (e.g., polonium-210; radon-222; polonium-210 and thorium-230), and of thorium and its daughters (e.g., radium-228; thorium-228, and radon-220) may be retained in the collected fly ash and bottom ash, caution must be exercised in the land disposal of these wastes where the rate of discharge exceeds 40 Mg/day (43).

3.1.2 Non-IERL/RTP Evaluations of the SRC Systems

Besides EPA, the United States Department of Energy (DOE) is the other sponsor of SRC environmental assessment activities. A summary of programs for which published data are available is presented in Table 14.

3.1.2.1 Pittsburg and Midway Engineering and Health Program (48)

The Pittsburg and Midway Coal Mining Company (P&M), the prime DOE contractor, is in charge of the overall Fort Lewis pilot plant operations. In addition to overseeing the engineering aspects of plant operations, P&M conducts a health program composed of the following: an industrial hygiene monitoring program, designed to provide quantitative data of the contaminant levels to which employees are exposed

TABLE 14. DOE SRC CONTRACTS AND SUBCONTRACTS HAVING PUBLISHED REPORTS OF ENVIRONMENTAL ASSESSMENT ACTIVITIES

Contractors and Subcontractors	Report Reference	Area of Research Reported on[a]	Program Technical Approach
Pittsburg & Midway	(48)	• Health Programs: Industrial hygiene program	Monitoring in pilot plant for potential air and skin contamination.
		Clinical examination program	Periodic visual skin examinations and pulmonary function tests.
		Educational program	Health protection indoctrination presentations
Washington State University[b]	(49)	• Chemical Programs: Analysis of trace element distribution in SRC-I	Utilization of neutron activation analysis (NAA) and atomic absorption spectroscopy (AAS)
Alsid, Snowden & Associates[b]	(50)	• Environmental sampling/ monitoring program	Ongoing air, water and foliage monitoring (sampling and analysis) studies of environment surrounding SRC pilot plant
Battelle Northwest Laboratories	(51)	• Chemical Program: Sampling and analysis characterization of SRC products, by-products and effluents	Development of appropriate sampling techniques. Inorganic analysis by utilizing NAA, x-ray florescence (XRF) and chemical speciation methods. During organic analysis, extracts are partitioned into acidic, basic, polynuclear aromatic and neutral fractions which are then analyzed by gas chromatography/ mass spectroscopy.

(continued)

TABLE 14. (continued)

Contractors and Subcontractors	Report Reference	Area of Research Reported on[a]	Program Technical Approach
Consolidated Edison of NY and Electric Power Research Institute	( )[c]	SRC-II combustion test-emission data comparison to EPA standards	4500 barrels of SRC-II fuel were burned, followed by a comparison burn test using low-sulfur oil

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[a] The Fort Lewis pilot plant is the sample source of all programs listed

[b] Subcontractors to Pittsburg and Midway

[c] Work is still being conducted on the burn test. A final report is therefore not yet available

at various locations in the plant; a clinical examination program, an educational program, and a toxicological program. The employee orientation and education program has been generally successful. The toxicological program, which will utilize animal bioassays to determine toxicity of various materials, is in its early stages. A data summary of these four health program efforts for the period January 1, 1974 to June 30, 1977 follows.

The major industrial hygiene monitoring studies accomplished thus far include the following results:

- Airborne Organic Vapors - 120 organic vapor samples were collected and results indicate that in-plant concentrations of organic vapors and hydrocarbon gases were generally less than 0.1 ppm.
- Benzene Survey - two liquid streams (naphtha and middle distillate) in the SRC process have benzene concentrations great enough to require actions to comply with the Benzene Standards as proposed by the Occupational Safety and Health Administration (29 CFR Part 1910, Federal Register dated May 27, 1977). Each of these two streams normally has a benzene concentration greater than 0.1 percent but less than 1 percent volume percent. Air sampling results indicate occupational exposures to benzene were far below the 1 ppm time weighted average level as specified in the proposed standard.
- Suspended Particulates - nearly two hundred suspended particulate samples have been collected with high volume air samplers and personal air sampling pumps. In addition to determination of

total mass collected, some of these samples have been analyzed for benzene soluble fractions and specific polynuclear aromatic hydrocarbon compounds. Analytical data so far showed fairly inconsistent and scattered results in terms of the ratio between benzene soluble fraction versus the total mass concentration for particulates from the same plant areas.

- Welding Fumes Study - this is a study of welders' exposure to coal tar and liquids when cutting or welding contaminated parts. Results so far show that welders could be exposed to high concentrations of coal-derived materials as evidenced by the presence of elevated benzene solubles fractions in the welding fumes.

- Asbestos Survey - the only known source of asbestos is the filter aid (basecoat) material, "Fibra-Flow." Results of several surveys show that occupational exposures to asbestos have been brought under control by the installation of an asbestos handling glove box and by stringent work practices and respiratory protection. Later air sampling results showed asbestos concentration of less than 0.1 fiber per ml of air.

- Free Silica and Mineral Residue Dust - several types of calcined diatomaceous earth containing 50 percent by weight of free silica were used as filter aid in the filter preparation building. Dust concentrations as high as 10 mg/m^3 have been monitored. The situation is controlled by a mandatory respirator program. The mineral residue contained an average of 4.5 percent free silica as α-quartz. Occupational free silica exposure could become a problem for future commercial SRC facilities because of the large quantities of mineral residue to be handled.

- Hydrogen Sulfide Study - potential H_2S release sources in the pilot plant were identified. Thirty-four H_2S samples showed H_2S concentration mostly below 0.1 ppm, indicating insignificant chronic H_2S exposure problem. It is predicted that H_2S will not present a chronic occupational exposure problem for future commercial-sized SRC facilities.

- Sulfur Dioxide Study - potential SO_2 release sources in the pilot plant have been identified. Forty-two SO_2 samples collected showed less than 0.1 ppm SO_2, indicating no occupational exposure problem. It is predicted that SO_2 will not present a serious threat to the health and safety of plant workers in future commercial-sized SRC operations.

- Phenols Study - phenolic compounds exist in large quantities in many liquid streams. However, 78 samples showed virtually no airborne phenols in the workplace. It is concluded that phenolic compounds may present serious occupational skin contact hazards in SRC processing but present no inhalation hazard.

- Noise Survey - plant noise and occupational noise exposure surveys were conducted. Results indicate that the SRC pilot plant has minimal occupational noise exposure as defined by noise dosimetry personnel monitoring.

- Carbon Monoxide Study - results of plant CO survey show that the major CO hazard in the SRC pilot plant was related to the use of plant inert gas which contains 1.5 percent CO. For a full-sized SRC facility, CO should be much less in the inert gas because of better combustion control and better inert gas generation equipment.

- Settleable Particulates - monthly samples of settleable particulates have been collected at six fixed sampling stations. Results indicate that, except for one month (November 15 to December 15, 1976), dustfall concentrations reported from the SRC pilot plant's sampling stations were considerably lower than those reported from a nearby urban community.

- Skin Contamination Study - preliminary work has been done towards developing a method for determining skin contamination by coal derived liquids. This methodology is still under development and no data are yet available from the study.

P&M's clinical program has been in effect since 1974 primarily for preemployment medical examinations and an annual follow-up. The purpose of the program is to detect at an early stage any changes in the various bodily functions. To date, there have been a few cases of mild transient photodermatitis from exposure to the SRC materials but no permanent or serious problems have been identified at this time.

The education program has also been in effect since 1974, primarily to advise the employee of potential health hazards, protective measures, and personal hygiene practices. New employees receive a health protection indoctrination which includes an audio-visual slide presentation and a health protection manual. Periodically, additional presentations are made to all employees on various health aspects, such as first aid, health and hygiene, and toxic hazards. Generally, such presentations are now scheduled at a frequency of about three per year.

The toxicological program is still in the early stages with only pilot studies (dose levels) and part of the acute inhalation study completed. Substantial mice mortalities were experienced in initial skin painting trials with the light oil, wash solvent, and wet mineral residue, probably because of improper dose levels when phenol concentrations in these materials are taken into consideration. A pilot study was then performed to establish dose levels, but, near the end of the study, some corneal opacity was detected in some of the animals, including the controls. A further 30-day inhalation study was then initiated to study this effect further, but, to date, this effect has not reappeared. Some analytical development work remains to be completed for a procedure to sample and analyze the atmosphere in the inhalation chambers prior to the initiation of the long-term inhalation studies. These and the two-year skin painting studies are expected to be initiated in the near future. The toxicology program is in a state of revision; details of the revised program are not yet available.

3.1.2.2 Trace Element Investigation by Washington State University

Washington State University, subcontractor to Pittsburg and Midway Coal Mining Company, is conducting an analytical study of the distribution and fate of 34 trace elements in the SRC process. A report of work performed during the period of August 1, 1974 to July 31, 1976 is available (49).

Neutron activation analysis was used to determine Ti, V, Ca, Mg, Al, Cl, Mn, As, Sb, Se, Hg, Br, Co, Ni, Cr, Fe, Na, Rb, Cs, K, Sc, Tb, Eu, Sm, Ce, La, Sr, Ba, Th, Hf, Ta, Ga, Zr, and Cu in feed coals, process solvent, SRC, mineral residues, wet filter cake, by-product solvents, process and effluent waters and by-product sulfur. The sample points were chosen such that the major process streams were adequately described and that the major input and output materials were included. Atomic absorption spectrophotometry was used to measure the toxic elements Pb, Cd, and Be in plant-derived solvents, effluent water and Hamer Marsh water. Hamer marsh is located in the vicinity of the SRC pilot plant at Fort Lewis, Washington and receives treated SRC wastewater. Specific methods were developed for analysis of a wide range of material compositions. The neutron activation analysis procedures were divided into short and long irradiation procedures for elements with short half lives (less than 3 hours) and intermediate to long half lives (8 hours to 5.2 years).

Data are presented for preliminary SRC-I process materials and also for a set of materials taken during operation of the pilot plant but not under equilibrium conditions.

Two separate sets of samples were taken when the pilot plant had operated continuously for seven days and composite samples were collected for each process fraction over a 24-hour period. These are designated Equilibrium Sets 1 and 2. A material balance (or budget) was calculated for each element from the concentration data and the yields of each process fraction for each equilibrium set in the SRC process. The SRC and insoluble residue account for more than 95 percent of the input of each element (except for Hg and Co in Equilibrium Set 1) with other process fractions contributing little to the trace element balance. Except for Cl, Br, and Ti, each element was substantially lower in the SRC compared to the original feed coal.

3.1.2.3 Environmental Impact Assessment at Alsid, Snowden and Associates

Alsid, Snowden and Associates, subcontractor to Pittsburg and Midway Coal Mining Company, are conducting an environmental sampling/monitoring program to determine whether the SRC pilot plant has had any measureable impact on air quality, water quality, and vegetation in the surrounding environment.

Baseline studies were made on air and water quality (December 1972 to December 1973) prior to pilot plant construction. Ongoing monitoring studies of air and water quality and foliage effects were made (and are continuing) during plant operations. The published report (50), summarizing the environmental program for January 1, 1972, through June 30, 1977, indicates that the pilot plant had virtually no measureable impact on air and water quality in the surrounding environment. Foliage studies made during plant operations at areas that would be receptors of plant emissions and at control areas indicate that the pilot plant operation has had no discernible effect upon the vegetation.

In assessing air quality, samples of the following were collected and measured: suspended particulates, gaseous hydrocarbons, sulfur dioxide, oxides of nitrogen, carbon monoxide and carbon dioxide.

Water samples were collected once or twice monthly (during sampling phases) from eleven sampling stations and analyzed for the following physical, chemical and bacteriological parameters: temperature, dissolved oxygen (DO), dissolved oxygen percent saturation, specific conductance, turbidity, color, pH, sulfate, phenol, chemical oxygen demand (COD), total organic carbon (TOC), coliforms, nitrogen, phosphorous and various trace elements.

Foliage samples were collected to determine if growth abnormalities were present. Samples from all sites were compared in the field to determine variation between sites.

3.1.2.4 Three-Point SRC Program at Battelle Northwest

Battelle Northwest Laboratories is conducting three SRC studies - a chemical program, an ecological program, and a biomedical program. The chemical program will be discussed in this section, with the organic and inorganic analysis data being presented in other parts of Section 3.0. No published data are presently available from the biomedical and ecological program, although reports are to be issued in the near future.

The objective of the chemical program is to characterize products, by-products and effluents from the SRC conversion process. Inorganic analysis data of the feed coal, mineral residue, product solids and liquids, process liquids and effluent gases taken from the SRC pilot plant indicate that except for mercury, titantium and bromine, most elements appear to remain with the mineral residue. For the case of bromine, approximately 84 percent remains with the product, whereas for titanium, approximately 56 percent remains with the product. In the case of mercury, 89 percent is unaccounted for in the solid and liquid products and is presumably emitted in the process offgas. Product and effluent organic analysis data are presented in Section 3.4.

A major component of the Battelle chemical program are studies to determine aspects of SRC sampling and analysis which should be considered in order to be most effective in the following:

- Taking representative samples
- Interfacing with the plant and its personnel
- Avoiding sample contamination and degradation
- Choosing analytical techniques which minimize matrix effects.

These aspects of the chemical program are presented in Fruchter and Peterson, 1978 (51), and will also be incorporated in a "program planning document," presently being prepared by Battelle.

3.1.2.5 Combustion of SRC by EPRI and Consolidated Edison

Consolidated Edison of New York and the Electric Power Research Institute recently participated with DOE in conducting a burn test of 4500 barrels of SRC-II fuel. The purpose of the test was to determine if SRC-II was a satisfactory substitute for low-sulfur oil and if it would meet the EPA proposed emission standards. Although work is still being done with regard to the burn test and a final report is not yet available, reported results appear "very encouraging" with regard to the combustion and emission qualities of SRC-II. Data from this study are presented in Section 5.5.

3.2 Input Materials

Input streams are the raw materials that must be supplied to the processes of the SRC-II system. These input streams will include primary and secondary raw materials, and the output streams from other processes. The primary raw materials used in the SRC-II system consist of coal, water and air. The secondary raw materials consist of detergents, catalysts, and additives produced by technologies other than the SRC-II system. The raw materials used in the four system operations of the SRC system, per se, are shown in Table 15, while those used in various auxiliary processes are shown in Table 16.

3.2.1 Regional Characterization of U.S. Coals

Because the chemical composition and other characteristics of the coal and water materials that are supplied to processes of the SRC-II system are quite site-specific, it is essential to resort to generalized characterization of these materials on a regional basis.

TABLE 15. PRIMARY AND SECONDARY RAW MATERIALS SUPPLIED TO SRC OPERATIONS AND AUXILIARY PROCESSES (6)

Process or Operation	Primary Raw Materials	Mg/day	Secondary Raw Materials	Mg/day
Coal pretreatment	• coal from coal receiving and storage	29,732	• fuel gas/air mixture	3,601
	• air to coal dryers	29,827		
	• makeup water	2,028		
	• moisture from environment	60.6		
Liquefaction	• treated water from water supply	2,411	• fuel gas to preheater	691
	• air to preheater	12,725		
Separation				
Gas separation	None	----	None	----
Solids/liquids separation	• cooling water for solidifying the SRC-II residue	unquantified	• fuel gas/air mixture	4,537
Purification & Upgrading				
Fractionation	None	----	• fuel gas/air mixture	7,579
Hydrotreating	• water to oil-water separator (decanter)	775	• fuel gas/air mixture	1,543
			• catalysts	unquantified

TABLE 16. PRIMARY AND SECONDARY RAW MATERIALS SUPPLIED TO AUXILIARY PROCESSES (6)

Process	Primary Raw Materials	Mg/day	Secondary Raw Materials	Mg/day
• Coal receiving and storage	raw coal	29,740		
• Water supply	raw water	32,057	chemicals used in water treatment	14
• Water cooling	makeup water boiler blowdown	23,092	chlorine disinfectant plus chromate inhibitor	unquantified
• Steam and power generation	coal	929	recycled water from	13,345
	makeup water	4,677		
	air	11,087		
• Hydrogen generation	coal	1,392	oxygen	2,551
	water	671	steam	4,064
	air	965	monomethanolamine sol.	0.9
			fuel gas	52
			makeup catalyst to shift converter	unquantified
• Oxygen generation	cooling water	14,913		
	air	11,650		
• Acid gas removal	makeup water	3	stream to amine regeneration	unquantified
			monoethanolamine	0.8

(continued)

TABLE 16. (continued)

Process	Primary Raw Materials	Mg/day	Secondary Raw Materials	Mg/day
• Sulfur recovery	water	74	fuel gas	8
	air for oxidation	4,882		
	air for combustion	146		
• Hydrocarbon & hydrogen recovery	cooling water	unquantified	steam	unquantified
• Ammonia recovery	air	14,786	calcium hydroxide solvent	7
• Phenol recovery	none	----	makeup naphtha solvent	3
			hydrochloric acid	31

The coal characteristics considered to be of greatest importance in the siting and operation of SRC systems include the following (52):

- Coal rank (characterized as bituminous, subbituminous, and lignite) determines the size of equipment required to clean the coal
- Recoverable coal resources and reserves (surface and underground) determine the siting of SRC liquefaction systems
- Proximate analyses (moisture, ash, volatile matter, heating value and fixed carbon)
- Ultimate analyses (carbon, hydrogen, oxygen, nitrogen, and sulfur)

Seven regions of major coal reserves have been included in this study; these regions and associated coal types are shown in Table 17.

Both the chemical and physical properties of coal will exert an effect on the performance and size of the equipment needed for the operation of the SRC system. The proximate and ultimate coal analyses presented in Tables 18 and 19 include only sulfur, nitrogen, and ash as major non-fuel components. Most of these parameters will require evaluation when a specific site is selected for the commercial SRC system:

- Sulfur - three forms of sulfur can occur in coal, organic, pyritic, and sulfate. In general, sulfate sulfur amounts to only a few percent of the total

TABLE 17. GEOGRAPHICAL DISTRIBUTION OF MAJOR COAL RESOURCES AND RESERVES (53)

EPA Regions	Coal Region	States Included (wholly or in part)	Coal Rank	Surface Mineable Coals Resources	Reserves
III,IV,V	Appalachian	Pennsylvania Ohio West Virginia Kentucky	Bituminous	15,124	3,727.
IV,V	Eastern Interior	Illinois Indiana Kentucky	Bituminous	16,230.	4,002.
VI	Texas Gulf	New Mexico Texas	Subbituminous Lignite	2,631	181
VIII	Fort Union - Powder River	North Dakota South Dakota Montana Wyoming	Lignite and Subbituminous	25,136.*	18,347
VI,VIII,IX	Four Corners	New Mexico Colorado Utah Arizona	Subbituminous	3,556.**	2,772.**
X	Northern Alaska	Alaska	Bituminous and Subbitumious	14,219	106,000

* does not include South Dakota resources or reserves

**does not include Colorado and Utah resources or reserves

TABLE 18. AVERAGE PROXIMATE ANALYSIS OF COAL BY REGIONS

Region	Coal Rank	Heating Value Btu/lb	Moisture(1) %	Volatile Matter %	Fixed Carbon %	Ash %	Sulfur (53) %
Appalachia	Bituminous	13570	3.4	30.6	56.5	7.7	1.8
Eastern Interior	Bituminous	11630	11.2	35.2	40.7	9.4	3.5
Fort Union	Lignite	6870	37.5	27.6	28.1	6.2	0.6
Powder River	Sub-Bituminous	9780	19.1	34.4	40.6	5.3	0.6
Four Corners	Sub-Bituminous	10160	11.4	33.8	40.0	14.1	0.7

(1) As received basis

(2) Sulfur is distributed between the volatile matter as organic sulfur and the ash (or mineral matter) as pyrite.

TABLE 19. ULTIMATE ANALYSIS OF COAL BY REGION (53)

Region	Moisture	Ash	C	H	O	N	S
Appalachian	3.40	7.70	76.37	4.45	5.27	1.01	1.80
Eastern Interior	11.20	9.40	64.32	4.15	6.15	1.28	3.50
Fort Union	37.50	6.20	41.13	2.73	11.03	0.81	0.60
Powder River	19.10	5.30	56.70	4.00	13.00	1.30	0.60
Four Corners	11.40	14.10	58.29	3.90	10.29	1.32	0.70

(1) In percent

sulfur and tends to be associated with the mineral matter. Organic and pyritic sulfur are the more important forms.

Organic sulfur compounds which are reported to exist in coal and in crude coal-derived products include mercaptans, sulfides and disulfides, and homoglogs of thiophene. Organic sulfur makes up from 20 percent to 80 percent of the total sulfur content of coal. Distribution of organic sulfur is relatively uniform from top to bottom of the coal seam. Sulfur organically bound to the coal structure cannot be effectively removed by mechanical or wet cleaning methods.

Sulfur present as iron pyrite, FeS, is part of the mineral matter. It can occur associated with inclusions of other minerals in the coal seam, as inclusions of pyritic masses, or as veins of particles distributed throughout the seam. Some seams have higher concentrations of pyritic sulfur at the top and bottom than throughout. Depending upon the manner of occurrence, crushing or grinding may be used to physically separate the pyritic material from the coal. The higher density of the pyrite then permits its separation to a greater or lesser extent from the bulk of the coal by gravity techniques.

- Ash - ash or mineral matter occurs in coal as true mineral components, rock, overburden, partings, and pyrite or to a lesser extent as mineral forming inorganic elements combined chemically into the coal structure. Some water in the form of water of hydration may be present in the mineral matter. Ash constitues varying percentages of the coal and, if it originates from overburden included during mining, may be higher in the mined coal than in the seam proper. Crushing and cleaning can be used to reduce mineral matter resulting from partings, inclusions, overburden, and pyrites.

Other major components and minor or trace elements can include virtually all the other mineral elements. Mineral elements in coal can influence filtration capacities, the amount of slag generated, and the ease of dissolution of coal in the liquefaction process. For example, coals with high sodium or iron content are reportedly more readily dissolved than low-iron coals. Coals having low amounts of these promoters may require the outright addition of catalysts that promote dissolution. Combustion of coal converts mineral matter to oxides which form ash or slag depending upon temperature. Some oxides such as those of lead, mercury, vanadium, and boron may be volatilized.

Fusion temperature and viscosity are the physical properties of the ash which are of interest.

- Moisture - coal moisture content is affected by moisture added to the coal by washing or weathering, and moisture lost from the coal by exposure to dry air. In some formations, the coal seam may be an aquifer yielding higher as-mined moisture content. Surface moisture usually is not included in coal moisture.

Moisture reduces the available heat from a given coal by two mechanisms. Its presence increases the total weight of the coal contributing nothing to the heating value. In combustion, the moisture is heated from ambient temperature to the exhaust temperature of the combustion gas and the coal moisture, as water vapor or steam, carries with it sensible heat, heat of vaporization and superheat, all of which are unrecoverable.

- Oxygen - excess oxygen in the coal requires more hydrogen gas to convert it to water.

- Nitrogen - nitrogen in coal is exclusively associated with the organic materials. Possible modes of occurrence are as amines and heterocyclic nitrogen compounds. Nitrogen contents of coal are on the order of a few percent maximum. Because nitrogen is relatively inert it is primarily a diluent in the coal. However, compounds which may be produced in coal liquefaction processes may be undesirable. For example, the amine or ring compounds may be retained as intact constituents of the products in liquefaction processes.

- Chlorine, Phosphorus, and Other Elements - other elements present in the coal are not usually reported in the Ultimate Analysis. Chlorine is an example and, although analytical techniques for its determination exist, it usually is not determined unless a specific need for its analysis exists. Chlorine usually amounts to only a fraction of a percent. Phosphorus, associated with the mineral matter, usually is not determined, although its level may present environmental problems in some coals.

Coals containing unusually high concentrations of specific elements, for example selenium, fluorine, vanadium, or arsenic may pose special pollution or boiler fouling problems; these would require evaluation on a site-specific basis.

- Physical Properties - grinding, washing, and plastic properties of the coal are of importance in determining the coal pretreatment steps required prior to use in the SRC-II system. Processing equipment for coal pretreatment will depend upon the grinding characteristics of the coal used. Grindability is influenced by other coal properties such as hardness and strength.

  Washability tests are conducted to determine the ability of the coal to be cleaned of mineral matter (including pryitic sulfur) prior to use. Float/sink separations indicate the appropriate gravities which separate heavier minerals containing refuse from relatively cleaner coal.

  The plastic properties of coal are related to the softening of the material during heating. Tests to measure these characteristics are generally empirical. Fusible coals will require blending with other coals or pretreatment to control this property to acceptable levels prior to use in some refining processes.

3.2.1.1 Estimation of the "Average" and "Maximum" Composition of U.S. Coals

In developing a technique for estimating the average and maximum composition of SRC process and waste streams (i.e. the worst case) sets of values for the "average" and the "maximum" elemental composition of all U.S. coals were first established. In this approach, the rationale was to treat all published averages and maximum as if they were raw data. The next important step was to derive from the published data of Filby et al. (49) and of Gehrs et al. (54) on SRC wastes and residues applicable partitioning factors, as discussed in Section 3.1.1.4. Since the coal composition estimated by use of the partitioning factors are based on actual data that have been generalized to all U.S. coals, it appears desirable, on the basis of the need in the SRC assessment to establish realistic worst cases for the elemental composition of coals, to use these derived values in preference to actual composition based, generally, on one sample of coal whose composition was not reported. For the purposes of this report, the "average" U.S. coal is defined as that coal whose elemental composition is specified in Table 20, column 2, under the term "arithemetic mean." The "maximum" U.S. coal (i.e., the worst case) is that coal whose elemental composition, as specified in Table 20, column 5, under the heading "range", is described by the highest (or last) number.

3.2.2 Regional Characterization of U.S. Surface and Groundwaters

Some indication of the great variations in the quality of surface and groundwaters of the United States can be found in the series of hydrologic and related maps presented

TABLE 20. AVERAGE AND MAXIMUM ELEMENTAL COMPOSITION OF ALL U.S. COALS FOR WHICH DATA HAVE BEEN PUBLISHED

Name	Number of Surveys	Arithmetic Mean*	Geometric Mean*	Unbiased Standard Deviation*	Range*
Aluminum	6	13,400	13,000	3,600	9700-18,500
Antimony	12	2.2	1.8	9.3	0.48-5
Arsenic	26	10.9	7.5	9.3	0.828-35
Barium	8				500
Beryllium	11	1.4	1.1	0.9	0.2-3.
Boron	27	55.	42.	37.	7.-120.
Bromine	8	16.	14.	10.	4.7-36.1
Cadmium	16	3.4	1.4	4.5	0.1-16.2
Calcium	9	7700.	6400.	4700.	2000.-17,000.
Cerium	4	18.	17.	6.	11.-25.
Cesium	6	1.2	0.83	0.76	0.11-2.
Chlorine	7	1000.	890.	510.	300-1700.
Chromium	32	16.3	13.8	8.0	1.5-39.4
Cobalt	31	10.2	8.0	6.5	1.02-25.
Copper	29	12.7	11.2	6.6	3.2-33.8
Dysprosium	3	1.3	1.2	0.9	0.63-2.3
Europium	5	0.32	0.31	0.12	0.2-0.52
Fluorine	20	78.	73.	34.	30.-160.
Gallium	11	4.4	4.1	1.5	2.-7.
Germanium	10	6.2	4.5	4.5	0.91-14.
Hafnium	5	0.82	0.80	0.24	0.54-1.2
Indium	4	0.17	0.16	0.06	0.1-0.23
Iodine	3	1.3	1.1	0.7	0.52-1.7
Iron	10	14800	11900	9500	2890-33000.
Lanthanum	13	9.6	9.1	3.2	5.1-15.
Lead	22	13.	3.4	19.	0.02-64.9
Lithium	15	35.	29.	22.	11-78.
Lutetium	4	0.13	0.12	0.07	0.07-0.22
Magnesium	6	1120.	900.	890.	500-2800.
Manganese	25	36.	23.	34.	1.42-138.
Mercury	19	0.15	0.11	0.15	0.012-0.73
Molybdenum	29	5.2	4.0	3.1	0.08-12.
Nickel	30[a]	19.[a]	15.[a]	21.[a]	3.3-121[a]
Niobium	2	1.8	1.7	0.4	1.5- 2
Phosphorus	4	104.	97.	43.	64.-150.
Potassium	10	2300.	1900.	1300.	500-5000
Rubidium	8	28.	18.	30.	4.6-100.
Samarium	4	1.53	1.34	0.84	0.61-2.6
Scandium	9	3.5	3.2	1.5	1.43-5.89
Selenium	26	4.0	3.4	2.3	0.8-10.4

(continued)

TABLE 20. (continued)

Name	Number of Surveys	Arithmetic Mean*	Geometric Mean*	Unbiased Standard Deviation*	Range*
Silicon	5	22800	22500	4300.	17000-28000
Silver	5	0.17	0.06	0.30	0.02-0.7
Sodium	13	2000.	18000.	14000.	7600-36000
Strontium	7	120.	90.	0.09	0.15-0.33
Sulfur	3	22000.	18000.	14000.	7600-36000
Tantalum	5	0.24	0.22	0.09	0.15-0.33
Tellurium	3	0.025	0.025	0.005	0.02-0.03
Terbium	4	0.20	0.13	0.13	0.02-0.34
Thallium	1	0.66			
Thorium	12	4.5	4.0	2.2	1.9-9.7
Tin	21	2.0	1.7	1.2	0.4-5.
Titanium	14	530.	250.	340.	0.052-1135.
Tungsten	4	0.72	0.72	0.09	0.62-0.82
Uranium	17	2.2	1.8	1.7	0.68-8.1
Vanadium	29	26.	24.	11.	4.-50.
Yttrium	5	10.4	10.1	3.0	7.4-14.
Ytterbium	5	0.63	0.61	0.17	0.38-0.83
Zinc	28	120.	36.	280.	0.05-1460
Zirconium	21	57.	49.	25.	7.6-110.

*ppm, wt. basis

[a] deletes one survey of Pennsylvania coal which had 4,480 ppm nickel. Next highest nickel concentration was 121 ppm in a Utah coal.

in Appendix C. Any narrative summary of water quality in an area as large as the U.S., with its broad variations in natural and cultural features, is extremely difficult. All of this suggests the truism that there is a wide range of water quality indices in the United States. Aside from this, however, it is possible to summarize those aspects of water quality which might present problems to the operation of SRC-II systems in coal-bearing states of the various EPA regions.

3.2.2.1 EPA Regions III, IV and V (Pennsylvania, Ohio, West Virginia, Kentucky, Illinois, and Indiana)

3.2.2.1.1 Pennsylvania, Ohio, West Virginia, Eastern Kentucky

The quality of surface water in these coal bearing states is affected by changes in water and land use patterns (industry, surface mining, etc.), high and low flow patterns, degree of weathering and accelerated erosion, and rock types. In the greater part of the region, the concentration of total dissolved solids (TDS) in surface waters is less than 300 ppm, with a range from 50-5000 ppm (53). Selected water quality characteristics for major drainage basins in these regions are shown in the Appendices.

Existing uses of surface waters include: municipal; industrial; irrigation of crops and food processing; mining and steam electric stations. The riparian concept of surface water rights is adhered to throughout these regions. Some of the states have adopted the rule that surface water can be utilized so long as the proposed use is consistent with similar uses by other riparian owners (53). Groundwater quality in most locations is satisfactory for domestic and other uses; however, some problems may arise from SRC-II systems in some areas having unusually hard waters, excess iron, and salinity. In many river basins of these regions, groundwater will continue to be a major source of water supply for industrial use (53).

3.2.2.1.2 Illinois, Indiana, Western Kentucky

In parts of these regions, surface water quality problems occur as a result of acid mine drainage and the discharge of industrial wastes (53); these and related problems will need careful attention on a site-specific basis. The hardness of surface waters is a problem in the northern portions of Illinois, and dissolved solids may range from 200-700 ppm (or higher) during stream low flows of the summer months, during which time the groundwater contributes extensively to stream low-flows. Recent stream quality data from these regions indicate that the trace elements occur at higher levels in surface waters in these regions than in any of the others (55). In fact, many of the metals exceeded the stringent aquatic-life standards at several of the National Stream Quality Accounting Network (NASQAN) stations (U.S.). Suspended sediment concentrations range from over 1900 ppm, in western and southern Illinois to less than 270 ppm in western Kentucky. The riparian concept of surface water rights is adhered to in these states.

Groundwater quality varies widely depending upon depth and type of aquifer. For example, in the alluvial and glacial drift aquifers, the water quality is good, but the iron content exceeds 0.3 ppm and water harndess exceeds 250 ppm. In the deep aquifers, water hardness ranges from 300-500 ppm, salinity exceeds 1000 ppm and sulfate concentration can exceed 250 ppm. Groundwater is heavily used by rural homes, cities, towns, and industries in these regions. In some river basins, all of the municipal water supply is obtained from aqufiers (53).

3.2.2.2 EPA Region VI (Northeastern Texas and Northwestern New Mexico

3.2.2.2.1 Northeastern Texas

As would be expected, the surface water quality in this area is very site specific. For example, salinity problems occur in the tributaries abutting oil fields (brines). The Trinity River basin reportedly suffers from serious pollution from municipal discharges; these produce severe dissolved oxygen deficits at times. The Brazos and Colorado Rivers to the south suffer from chornic salinity problems due to the inflows of naturally saline waters. In the Navasota River basin, oil field wastes produce periodic problems in the tributaries and main stream of the Navasota River. In the Guadalupe and San Antonio River basins, dissolved solids are a problem, ranging from 300 ppm up to more than 600 ppm at low flows. Work has been initiated to improve the surface water quality in these areas.

Surface water supplies are most plentiful in the northern portion of this area. The combined water surpluses for the Sulphur, Cypress and Sabine basins in the year 2020 reportedly will exceed 400,758 m^3 per year. If additional reservoirs can be realized, more than 2.426 million m^3 per year of additional water per year would be available. The availability of surface waters descreases to the south of the Sabine River. The demand for water in the Neches, Trinity, Guadalupe and San Antonio basins reportedly will exactly balance the supply, after augmentation from the Texas Water System or from other basins (53).

The water rights doctrine presently in use includes both the ripiarian and appropriation doctrines. Riparian rights exist incidental to land ownership, while the Texas Water Rights commission has discretionary powers of appropriation.

Groundwater availability is reported to be maximal, both with reference to the estimated safe yield and surplus of the Texas Water Plan for the counties of Brazos, Burleson, Washington, and Bastrop. However, throughout the Texas lignite area, aquifer recharge and water transmission will present some problems in water availability (53).

3.2.2.2.2 Northwestern New Mexico

The San Juan River displays increasing levels of dissolved solids, hardness, and sulfate as one proceeds downstream toward Farmington, New Mexico. Suspended sediment loads are reported to be highest during summer storm flows in the San Juan River.

Water use in New Mexico is regulated by the Colorado River Basin Compact of 1922, wherein New Mexico is allocated about 11 percent, or 790,262 m^3 per year, from the Upper Colorado River Basin system. The largest current allocation in New Mexico goes to the Navajo Indian Reservation Project (58). Irrigation is the largest water use in the San Juan River, at an estimated 264,451 m^3 per year.

Alluvial aquifers in the mainstem of the San Juan River valley are reported to have an assured and constant recharge. Wells in certain alluvial aquifers may yield more than 500 gpm at depths of about 21.3 m. The general yields, however, range from 18.5-185 gpm.

Groundwater quality of bedrock aquifers in the San Juan basin is considered poor with a dissolved solids content of more than 1,000 ppm, with some exceptions such as the San Jose and Nacimiento formations where the dissolved solids may be lower or higher than 1,000 ppm (53).

3.2.2.3 EPA Region VIII (Western North Dakota, Eastern Montana, Eastern Wyoming, Eastern Utah, and Northwestern Colorado)

Information on average dissolved chloride, dissolved sulfate, alkalinity, dissolved fluoride, hardness, dissolved solids, total nitrogen, and phosphorus for this region is given in the Appendix for the Missouri, Yellowstone and Bighorn Rivers and their tributaries. In the Western Dakota sub-basin, surface water quality of most streams is considered poor because of excessive, periodic overland flows (i.e., surface runoff) intermittent stream flows, and leaching of rocks and soils containing high concentrations of water soluble salts (53); these salts include sodium sulfate, chloride, and bicarbonates.

Crop irrigation is considered the major water use in this region; however, extensive industrial options and applications for water in this region range from 0.878 million to 2.529 million cubic meters per year. Water rights in this region are regulated by each state under the so-called appropriation doctrine. For example, under the Yellowstone River Compact of 1950, 80 percent of the unused and unappropriated water of the Bighorn River is apportioned to the state of Wyoming and 20 percent to the state of Montana (53).

Groundwater quality of this region is highly variable, with hardness ranging from hard to very hard. The type of groundwater varies from calcium bicarbonate or calcium sulfate, to sodium or magnesium sulfate in the more widespread glacial-drift and outwash aquifers. Bedrock aquifers containing coal or lignite have TDS concentrations ranging from less than 500 ppm to more than 6000 ppm. The paleozoic bedrock aquifers in North Dakota have TDS ranging from 200,000 to 300,000 ppm (53). In Wyoming and other states of the region, groundwater is considered the most dependable source for domestic and livestock purposes (53).

3.2.2.4 EPA Regions VIII and IX (Southwestern Colorado and Arizona)

3.2.2.4.1 Arizona

Suspended sediment loads can become a problem in the Little Colorado River area of northeastern Arizona during summer storm flows. Surface water quality is highly variable, not only because of variable low flows, but also as a result of irrigation and industrial use return flows to surface waters. Additional information on surface water quality is shown in the Appendices.

Major water uses in the Little Colorado River basin include crop irrigation and mining (particularly in the Black Mesa coalfield). Surface waters are in extremely short supply. The water rights doctrine of appropriation is controlled by the State Engineers Office (53).

Groundwater supply from wells in alluvial aquifers along the Chinle Wash directly east of the Black Mesa coalfield in northeastern Arizona may be as high as 3400 lpm.

Wells in bedrock aquifers of the Black Mesa coalfield may yield from 39 to 1860 lpm (particularly in the northwestern half of the Black Mesa field) (53).

Groundwater quality in the Black Mesa area is hampered by dissolved solids levels ranging from 100 to 25,000 ppm. Water hardness and sulfate levels are highly variable (58).

3.2.2.4.2 Colorado

Information presented for the San Juan River basin (under New Mexico) is directly applicable to the southwestern corner of Colorado, where the state's major coal resources are located.

3.2.2.5 EPA Region X (Northern Alaska)

Surface water quality data for northern Alaska are limited, and long-term records are nonexistent (53). However, data on the Colville River (the largest stream in the region) have been collected intermittently since 1953, for dissolved solids, hardness, pH, sulfate, iron, calcium, silica and other constituents. Summary data for this region's water quality are shown in the Appendices.

During the winter months, the Colville River freezes solid to depth of 1.8 to 2.7 m. Measurements made in 1962, indicated zero flows from the end of October to the middle of May. Lakes of the region are usually less than 30 m deep and they freeze from 1.5 to 2.1 m each winter.

Considering the surface water problems, one turns to the groundwater as a source of water. Estimates of the sub-permafrost water suggest that this offers the potential for large-scale development, if the salinity and freezing problems can be solved. This approach, however, may prove uneconomical (53).

3.3 Process Streams

Process streams are defined as the output streams from the basic unit operations, and/or the various auxiliary processes that are input streams to another process in the technology (56). As in Section 3.2, this discussion begins with the process streams comprising the operations and processes that are unique to the conceptualized SRC-II system. Perintent information on the process streams of the operations and processes is given in Table 21, while similar data on the various categories of the auxiliary process streams are shown in Table 22.

Process wastewaters from the main operations and processes are usually considered to present potentially serious water quality problems because of the suspected presence therein of cyanides, complex phenols, ammonia, PAHs and dissolved solids. However, these pollutants would likely be of nominal concern if the main unit process wastewaters were to be recycled. Furthermore, the auxiliary process-related wastewaters account for slightly more than 10 times that from the basic unit operations. Further discussion of the chemical aspects of process wastewaters and leachates of solid wastes is given in Section 3.6.

3.3.1 Coal Pretreatment

The coal preparation module is diagrammed in Figure 15, and summarized in Table 21. By use of a series of jigs, screens, centrifuges, cyclones, and roll crushers the 76 mm

TABLE 21. PROCESS STREAMS ASSOCIATED WITH OPERATIONS AND AUXILIARY PROCESSES OF SRC-II (6)

Process or Operation	Process Stream From:	Process Stream To:	*Relative flow	Comments
1. Coal pretreatment	ROM coal storage area	3 mm cleaned, dried, and pulverized	$\frac{18,552}{29,732} = 0.62$	3 mm coal is conveyed from the pulverized coal storage bin to a slurry mixer. The coal to solvent (naphtha) ratio ranges typically from 1.5 to 2.5. Other raw materials composing this operation are water and air, as shown in Figure 16.
	Coal/solvent slurry from gas separation	The slurry is sent back to coal preparation	$\frac{36,364}{29,732} = 1.22$	This slurry is discharged from the intermediate flash separator of the gas separation operation, as shown in Figure 19.
2. Liquefaction	Coal/solvent feed slurry from coal preparation	The slurry is sent to the liquefaction dissolver to produce the complete feed stream for several other operations	$\frac{54,916}{29,732} = 1.85$	The coal solvent slurry is pumped into the liquefaction reactor along with treated water from the water supply process, hydrogen gas from the hydrocarbon recovery process, synthesis gas from hydrogen production process. The H_2:coal ratio is 1250 m^3 per Mg of coal.
	Hydrogen from from HC/H_2 recovery	To liquefaction	$\frac{538}{29,732} = 0.018$	
	Synthesis gas from hydrogen production process	To liquefaction fraction	$\frac{667}{29,732} = 0.22$	
Separation				
3. Gas separation	Solids/liquid slurry from the liquefaction reactor/dissolver	The slurry is sent to heat exchanger and pressure separation process	$\frac{58,532}{29,732} = 1.97$	The solid/liquid slurry remaining after passage through the intermediate pressure flash separation is split into two process streams, as shown in Figure 19.
	Flashed gases from the solids/liquids process	The flashed gases are sent to heat exchanger and to intermediate pressure condensate separation of liquid oils	$\frac{943}{29,732} = 0.032$	Light and heavy oils are sent to the fractionation tower as shown in Figure 13.
4. Solids/liquids separation	Concentrated bottom slurry remaining after the recovery of SRC liquids in the fractionation process	Feed flash vessel distillation and secondary flashing units of solid/liquids separation to recover liquid SRC	$\frac{9,311}{29,732} = 0.31$	The cooling water input shown in Figure 13 is required for the solidification of the SRC-II residue. Flashed gases from the initial flashing unit are routed back to the gas separation process, see Figures 19 and 23.

(continued)

TABLE 21. (continued)

Process or Operation	Process Stream From:	 To:	*Relative flow	Comments
Purification and Upgrading				
5. Fractionation	Solid/liquid slurry from the intermediate pressure flash separator of the gas separation process	The slurry is sent to the gas/fuel preheater to the fractionation process and eventual separation of SRC-II liquid, raw naphtha and fuel oil	$\frac{12,037}{29,732} = 0.40$	The bottom solids separated from input slurry are sent to the solid/liquids separation process for recovery of additional SRC-II liquid, as shown in Figure 31.
	Light & heavy condensed oils from the intermediate pressure condensate separator of the gas separation process	The oils are sent to the fractionation tower	$\frac{3,140}{29,732} = 0.11$	Raw naphtha and raw fuel oil are sent to the hydrotreating process, as shown in Figure 36.
6. Hydrotreating	Raw naphtha from fractionation tower	Preheater, guard reactor and catalytic hydrogenation unit	$\frac{525}{29,732} = 0.018$	The hydrotreating (i.e. hydrogenation) reaction, catalyzed by colbalt molybdate, converts organic sulfur and nitrogen compounds in the oils to H_2S and NH_3 which can be removed in the sulfur stripping and NH_3 stripping tower shown in Figure 36 and 13.
	Raw fuel oil from fractionation tower	Preheater, guard reactor and catalytic hydrogenation unit	$\frac{2,615}{29,732} = 0.088$	
	Catalyst (as seondary raw material)	Hydrotreating	unquantified	
	Synthesis gas from H_2 production	Hydrotreating	$\frac{270}{29,732} = 0.009$	

*Relative flow = $\frac{\text{Mg/day specified stream}}{\text{Mg/day feed coal}}$

TABLE 22. PROCESS STREAMS ASSOCIATED WITH AUXILIARY PROCESSES OF SRC-II (6)

Auxiliary Process	Process Stream From:	Process Stream To:	*Relative Flow	Comments
Coal receiving and storage	Raw coal from coal storage	Coal pretreatment	$\frac{29,740}{29,732} = 1.00$	The coal receiving and storage schematic is shown in Figure 15.
Water supply				
Water cooling	Recycle water from hydrogen production process	Water cooling	$\frac{245}{29,732} = 0.008$	
	Recycle water from wastewater treatment plant	Water cooling	$\frac{464}{29,732} = 0.016$	
Steam generation	Coal from coal pretreatment operation	Furnace and boiler units	$\frac{940}{29,732} = 0.032$	
Hydrogen generation	The SRC-II residue from solids/liquids separation is mixed with: coal from the coal pretreatment operation	The SRC-II residue plus coal becomes a source of hydrogen gas when reacted in the Koppers-Totzek gasifier	$\frac{2,753}{29,732} = 0.093$	Hydrogen gas is produced in the Koppers-Totzek gasifier
	Oxygen from oxygen generation	Koppers-Totzek gasifier	$\frac{2,551}{29,732} = 0.08$	
	Steam from steam generation	Koppers-Totzek gasifier	$\frac{4,060}{29,732} = 0.13$	
Oxygen generation	The primary raw materials are air and cooling water	The oxygen gas is routed to the hydrogen production process		The schematics for an oxygen generation process are given in Figures 37 and 38
Acid gas removal	Feed gases from gas separation and hydrotreating, primarily	MEA absorption tower, hence to the sulfur recovery process	$\frac{5,080}{29,732} = 0.17$	Only H_2S and CO_2 can be adsorbed on the MEA; and MEA is regenerated by thermal decomposition at elevated temperatures
Sulfur recovery	Feed gases from acid gas removal	Stretford absorber	$\frac{705}{29,732} = 0.024$	The absorbed H_2S is oxidized to elemental sulfur by the reduction of sodium metavanadate; acid gas removal process reportedly contains about nine percent H_2S by volume. Concentrations of H_2S in the treated tail gas are reported to range from 5-10 ppm.
	Feed gases hydrogen production	Stretford absorber	$\frac{5,912}{29,732} = 0.20$	

(continued)

TABLE 22. (continued)

Auxiliary Process	Process Stream From:	Process Stream To:	*Relative Flow	Comments
Hydrocarbon and hydrogen recovery	Purified gas from acid gas removal	This gas stream is first compressed and condensed in a multistage refrigeration unit, and then charged to a flash tower	$\frac{4,374}{29,372} = 0.15$	The flash gases are compressed and condensed in another multistage refrigeration unit, thence to a de-ethanizer column, where propane and butane are taken off the bottom and the overhead gases are charged to another cycle of distillation
Ammonia recovery	Combined process wastewaters from hydrotreating gas separation hydrocarbon/hydrogen recovery and several other processes of the SRC system	The ammonia bearing wastewater passes first into a rapid mix tank where the ambient pH is raised to 11.0 by addition of $Ca(OH)_2$ hence to clarifier. The clear liquid is sent to an NH_3 stripping unit	$\frac{3,932}{29,372} = 0.13$	Upward of 90 percent of the ammonia can be recovered by this method.
Phenol recovery	Sours water from gas separation	Phenol extraction unit using naphtha as solvent	$\frac{3,135}{29,732} = 0.11$	Upwards of 99 percent of the phenol can be removed after adjusting the pH of the sour (phenolic) water to pH 4.0 by the addition of HCl solution

*Relative flow = $\frac{\text{Mg/day specified stream}}{\text{Mg/day feed coal}}$

coal is cleaned and crushed to the minus 30 mm size, whereupon it is dried in a flow dryer and then pulverized to the minus 3 mm size. In the conceptualized SRC-II system producing 7950 m^3 of product per day, about 18,553 Mg of this pulverized coal is transferred daily by conveyor from a storage bin into a slurry mixer containing sufficient solvent. The coal to solvent ratio is about 1:2. This coal solvent slurry comprises the major feed input into the slurry preheater unit of the coal liquefaction operation.

The second process stream under coal pretreatment is the slurry discharged from the intermediate (Figure 16) flash separator of the gas separation process, the majority of which (about 75 percent) is reportedly routed back to coal pretreatment; this process stream consists of the original solvent, dissolved coal, and undissolved coal solids.

3.3.2 Coal Liquefaction

The coal liquefaction module is diagrammed in Figure 17. The only process stream is the coal/slurry mixture from coal pretreatment. The actual chemical composition of this stream is unreported, although it is known to contain gaseous hydrocarbons, light and heavy oils, coal residue plus ash, unreacted hydrogen gas, hydrogen sulfide, carbon monoxide, carbon dioxide, ammonia and nitrogen gases.

3.3.3 Separation

3.3.3.1 Gas Separation Process

In the gas separation process, the dissolver effluent/product slurry is received from the liquefaction reactor, whereupon it is cooled. On passage through a high pressure separator all of the uncondensed gases (e.g., H_2S and CO_2) are separated from the ambient liquids and routed to the acid gas removal process, while condensed hydrocarbons are sent to the fractionation process. The solids/liquids portion of the slurry from the high pressure separator is then passed sequentially through five processes in which the solids/liquids slurry is stripped of gases, ambient water, light oils, and heavy oils. The condensed oils become an input stream to fractionation. The remaining solids/liquids slurry from the high pressure separator is directed to an intermediate pressure flash separator. In this process, numerous hydrocarbons are again vaporized from the slurry in an intermediate pressure condensate separator. The remaining slurry emanating from the intermediate flash separator is split into two streams, the larger of which (36,364 Mg) is routed to coal pretreatment (see Section 3.3.1), and the smaller stream is sent to the fractionation process.

The flashed gases (about 943 Mg/day) from solids/liquids separation comprise the second process stream in the gas separation process. The composition and amount of uncondensible gases in the flash gas process stream are reported to be as follows (6):

Flash gas	Mg/Day
Carbon monoxide	58
Hydrogen gas	42
Hydrogen sulfide	10
Carbon dioxide	8.7
Ammonia	6.8

The amount of condensible hydrocarbons in the flash gas was reported to be 816 Mg/day (6).

3.3.3.2 Solids/Liquids Separation Process

The only process stream involved in this basic unit operation is the concentrated (bottoms) slurry from the fractionation process.

3.3.4 Purification and Upgrading

3.3.4.1 Fractionation Process

SRC products condensed from the fractionator column consist of raw naphtha, raw fuel oil and liquid SRC-II at 2726 Mg/day. The concentrated slurry remaining in the bottom of the fractionator (referred to as bottoms) is sent as a confined stream to solids/liquids separation.

The complete chemical characterization of, and the flow rates for the raw naphtha, raw fuel oil and the concentrated slurry have not been determined. However, the suspected presence of toxic and hazardous organic substances in the processed naphtha and fuel oil is discussed in Section 3.4.

3.3.4.2 Hydrotreating Process

As indicated earlier, the hydrotreating (i.e., hydrogeneration of feedstocks) process may not be specified in some SRC design systems; its use was retained to permit a more complete environmental assessment. The presence of suspected toxic and hazardous substances in the product naphtha and fuel oil is discussed in Section 3.4. The chemical composition of the feed gas (i.e., the synthesis gas from hydrogen generation) is discussed under Auxiliary Process streams in Section 3.3.5.

3.3.5 Auxiliary Processes

3.3.5.1 Hydrogen Generation

The input stream referred to as the SRC-II residue from the solids/liquids separation process, is mixed with coal (a primary raw material from the coal pretreatment operation); this stream qualifies as a process stream. The concentrations of various chemical compounds in the SRC-II residue have not been determined. The estimated inorganic element concentrations in the SRC-II residue, derived from the partitioning factor methodology discussed in Sections 3.2, are reported in Section 3.7.2.

3.3.5.2 Acid Gas Removal

The only process stream for this process consists of the off-gases from gas separation with the composition reported in Table 23. The makeup water is considered to be a primary raw material, and the additives to the amine system are secondary raw materials consisting of monoethanolamine (MEA), oleyl alcohol, and polyrad 1110A.

3.3.5.3 Hydrocarbon and Hydrogen Gas Recovery

The purified gas from the acid gas removal process reportedly has the composition shown in Table 24.

TABLE 23. CONCENTRATION OF ATMOSPHERIC EMISSIONS FROM THE OFF-GAS FROM GAS SEPARATION

Component	Concentration (Grams/cubic meter)
Ammonia	0.046
Carbon dioxide	66.
Carbon monoxide	91.
Hydrocarbons	810.
Hydrogen	130.
Hydrogen sulfide	97.
Nitrogen	4.2
Water	9.1

TABLE 24. CONCENTRATION IN THE ACID GAS TO SULFUR RECOVERY PROCESS STREAM

Component	Concentration (Grams/cubic meter)
Ammonia	0.050
Carbon dioxide	1.0
Carbon monoxide	110.
Hydrocarbons	940.
Hydrogen	150.
Nitrogen	6.5

3.3.5.4 Sulfur Recovery

The two process streams for this auxiliary process reportedly have the chemical composition shown in Table 25. The major constituents of the gas streams from both the acid gas removal and the hydrogen production processes are H_2S and CO_2.

3.3.5.5 Ammonia Recovery

This auxiliary process has one auxiliary process stream; namely the combined process wastewaters from several SRC processes, whose chemical composition is reported in Table 26.

3.3.5.6 Phenol Recovery

Only one input stream enters the phenol recovery process; namely, the process wastewater from gas separation whose chemical composition is estimated in Table 27.

3.3.5.7 Other Auxiliary Processes

The input streams into coal receiving and storage, water supply, water cooling, steam generation, and oxygen production are not considered process streams; rather, they typically conform to primary and secondary raw materials as defined in the Appendices.

3.4 Toxic Substances in Products and By-Products

The Fort Lewis plant has operated under varying process conditions, to produce either a solid or liquid fuel. Variations in process conditions can significantly affect

TABLE 25. CONCENTRATION OF STREAMS FROM GAS PURIFICATION AND HYDROGEN PRODUCTION (GRAMS/CUBIC METER)

Component	Gas from Gas Purification	Gas from Hydrogen Production
Ammonia	----	0.13
Ash	----	0.83
Carbon dioxide	442.	1200.
Carbon monoxide	2.2	---
Cyanide		0.28
Hydrocarbons	87.	---
Hydrogen sulfide	656.	18.
Nitrogen oxide	----	0.0011
Sulfur dioxide	----	0.2
Water	17.	

TABLE 26. CONCENTRATION IN WASTEWATER PROCESS STREAM FROM AMMONIA STRIPPING

Component	Concentration (Grams/Liter)
Ammonia	16.
Hydrocarbons	0.56
Hydrogen sulfide	13.
Phenol	0.18

TABLE 27. WASTEWATER FROM PHASE GAS SEPARATION

Component	Concentration (Grams/Liter)
Ammonia	17.
Hydrogen sulfide	13.
Phenol	11.

the physical characteristics, chemical composition and biological impact of the products and by-products. In examining field and laboratory data it is therefore important to specify whether the data source for the study was SRC-I (solid mode) or SRC-II (liquid mode).

As discussed in Section 2.0 of this report, the major differences between the SRC-I and SRC-II systems lie in the location of the solids/liquids separation process and the separation methods employed. In SRC-I the solids/liquids separation process precedes fractionation. The liquified coal slurry is filtered to remove the undissolved mineral matter (mineral residue) and the filtrate is flash distilled to remove the solvent, leaving a black liquid which solidifies on cooling. In the SRC-II fuel oil mode, some of the slurry is flash distilled leaving the mineral matter in the vacuum bottoms.

In both modes the distillate is further fractionated into light, medium, and heavy cuts. The light and medium cuts are treated by-products. The heavy cuts are either recycled as process solvent (solid product mode) or used as the fuel oil-type product (liquid mode). When operating in the liquid mode the product is the heavy distillate fraction, equivalent to about a No. 5 fuel oil (51).

An area of confusion that is encountered when examining data from SRC studies is the inconsistent terminology used to designate various product and by-product fractions. A partial listing of equivalent terms used to designate SRC-II fractions and the general boiling point range to which they refer, is presented in Table 28.

TABLE 28. SRC-II PRODUCT AND BY-PRODUCT TERMINOLOGY

Approximate bp Fraction	Terminology	Reference
<193°C	naphtha	41,50,51
	light cut	51
193°-249°C	middle distillate	41
	medium cut	51
	wash solvent	51
	fuel oil	6
249-454°C	heavy distillate	41
	distillates	50
	heavy cut	51
	fuel oil-type product	51
	SRC liquid	6
>454°C	residue (includes SRC, insoluble organic matter and ash)	41

Analyses of SRC product and by-products, performed by several investigators, will be summarized and briefly discussed in the following section. Filby and co-workers (49) of Washington State University conducted studies of the trace element distribution and fate in the SRC-I process. Their data forms the basis of the inorganic product composition and SAM/IA potential degree of hazard tables. Fruchter and Petersen of Battelle Northwest Laboratories, have conducted a program to characterize SRC products, by-products and effluents. Their analyses have been performed primarily on samples derived from the SRC-I process with limited analysis of SRC-II samples. SRC-II samples were used in a recent Level 1 sampling and analysis study by Hittman Associates. The nature of the methodology used does, however, restrict this preliminary data to qualitative/semi-quantitative interpretation.

3.4.1 Inorganic Analysis

3.4.1.1 SRC-I Partitioning Factors

Composition of various product and by-product streams is known to vary with the composition of the feed coal. An estimate of the concentration of the inorganic constituents in the naphtha, wash solvent, heavy oil, SRC-I, filter cake, and sulfur is presented in Tables 29 to 32. The tables are based largely on the data generated by Washington State University (49) with the incorporation of Battelle Northwest data (51).

3.4.1.2 SRC-II Level 1 Methodology and SAM/IA Analysis

Hittman Associates has completed a preliminary characterization of several SRC-II product and by-product streams according to Level 1 methodology. Spark source analysis and selective atomic absorption were run on naphtha, middle and heavy distillates. A complete Level 1 organic analysis was run on the middle and heavy distillates. The qualitative organic nature of the naphtha stream was determined by infrared analysis only.

3.4.1.3 Spark Source Results

Table 33 shows the results of spark source analysis for the product streams (naphtha, middle distillates and heavy distillates) and for the residue. The term residue refers to the bottom material remaining after fractionation and secondary flashing and contains SRC, insoluble organic material and ash. Residue is included in this discussion because it is most likely to be gasified to obtain useful energy content rather than be disposed of as a solid waste.

TABLE 29. PARTITIONING FACTORS AND ESTIMATED CONCENTRATION OF INORGANICS IN SRC-I LIGHT OIL-NAPHTHA

Name	Number of Deter-mination	Partitioning Factors: Arithmetic Mean	Partitioning Factors: Geometric Mean	Partitioning Factors: Unbiased Standard Deviation	Partitioning Factors: Range	Estimated Light Oil-Naphtha Concentration ug/1: Average	Estimated Light Oil-Naphtha Concentration ug/1: Maximum
Aluminum	2	0.0045	0.0044	0.0004	0.0042-0.0047	60,300.	83,250.
Antimony	5	0.11	0.0003	0.23	5.0x10^{-7}-0.53	242.	550.
Arsenic	7	0.0043	0.0002	0.0082	1.4x10^{-7}-0.0224	47.	150.
Barium	4	<0.016	<0.007	ca.0.018	<0.0016-<0.04	4.	8.
Bromine	5	0.017	0.002	0.030	4.9x10^{-6}-0.070	272.	614.
Calcium	5	<0.023	<0.017	ca.0.017	<0.0043-<0.049	<180,000	<390,000
Cerium	2	2x10^{-4}	2x10^{-4}	0.0	2-2x10^{-4}	3.6	5.0
Cesium	2	1.2x10^{-6}	1.1x10^{-6}	0.3x10^{-6}	0.92-1.4x10^{-6}	0.0014	0.0024
Chlorine	3	0.41	0.21	0.55	0.065-1.04	4.1x10^{5}	7.0x10^{5}
Chromium	4	0.009	0.001	0.014	3.4x10^{-7}-0.03	150.	350.
Cobalt	4	3.1x10^{-4}	0.16x10^{-4}	3.7x10^{-4}	3.5x10^{-7}-7.4x10^{-4}	3.2	7.8
Copper	4	0.020	0.006	0.034	0.0014-0.071	250.	680.
Europium	3	<0.10	<0.01	ca.0.17	<0.00028-<0.3	<32.	<52.
Gallium	2	<0.0015	<0.9.6x10^{-6}	ca.0.0021	3.1x10^{-8}-<0.003	6.6	10.
Hafnium	4	<0.0049	<0.0038	ca.0.0036	<0.0017-<0.009	4.0	5.9
Iron	4	7x10^{-4}	1x10^{-4}	12.x10^{-4}	0.013-2.5x10^{-3}	10,000	23,000
Lanthanum	4	0.0029	2.2x10^{-5}	4.8x10^{-3}	1.5x10^{-10}-0.010	28	44
Lead	2	<0.11	<0.05	ca.0.14	<0.0125-<0.21	1,400	7,100
Magnesium	2	ca.0.0065	ca.0.0062	<0.0030	>0.0044-<0.0086	ca.7300.	ca.18000
Manganese	3	0.0047	0.0045	>0.0017	<0.0028-0.006	170.	650.
Mercury	6	0.053	0.031	0.057	0.0032-0.16	7.9	39.
Nickel	5	<0.008	<0.004	ca.0.011	<0.002-<0.027	150	970
Potassium	4	<0.015	<0.001	ca.0.027	<6.4x10^{-5}-<0.055	34,500.	75,000
Rubidium	5	<0.010	<0.004	ca.0.017	<0.00085-<0.041	280.	1,000.
Samarium	3	0.010	6.3x10^{-5}	0.017	<6.1x10^{-9}-0.030	15.	26.
Scandium	3	5.7x10^{-4}	0.017x10^{-4}	9.8x10^{-4}	5.2x10^{-8}-0.0017	2.0	3.4
Selenium	6	0.037	0.005	0.064	7.7x10^{-6}-0.167	150.	380.
Sodium	4	0.0042	0.0023	0.0039	0.00023-0.0094	8400.	43000.
Strontium	4	0.013	0.006	0.016	0.00063-0.036	1600.	3400.
Tantalum	1	<2.9x10^{-6}	<2.9x10^{-6}		<2.9-<2.9x10^{-6}	7.0x10^{-4}	9.6x10^{-4}
Terbium	4	1.9x10^{-4}	0.02x10^{-4}	3.8x10^{-4}	3.1x10^{-7}-7.7x10^{-4}	0.038	0.065
Thorium	3	<5.2x10^{-4}	<5.2x10^{-4}	ca.0.2x10^{-4}	<5.0-<5.3x10^{-4}	2.3	5.0
Titanium	5	0.0032	0.0028	0.0014	0.00081-0.0042	1700.	3600.
Vanadium	3	0.014	0.008	0.011	0.0017- 0.24	360.	700.
Zinc	2	0.029	0.009	0.009	0.022-0.035	3500.	42000.
Zirconium	2	0.0012	0.0012	0.0001	0.0011- 0.0013	68.	132.
All arithmetic means above	36	0.029	0.004	0.072	1.2x10^{-6}-0.41		
All maximum above	36	0.09	0.01	0.20	1.4x10^{-6}-1.04		

TABLE 30. PARTITIONING FACTORS AND ESTIMATED CONCENTRATION OF INORGANICS IN SRC-I WASH SOLVENT

	Partitioning Factors					Estimated Wash Solvent Composition	
Name	Number of Determination	Arithmetic Mean	Geometric Mean	Unbiased Standard Deviation	Range	Average	Maximum
Aluminum	4	0.0015	0.0010	0.0014	0.00020-0.0036	1.7x10^{4}	2.4x10^{4}
Antimony	4	4.3x10^{-4}	0.2x10^{-4}	5.0x10^{-4}	<5x10^{-7}-9.3x10^{-4}	0.80	1.9
Arsenic	2	4.4x10^{-4}	0.5x10^{-4}	6.2x10^{-4}	0.034-8.8x10^{-4}	4.1	13.
Barium	4	<0.005	<0.002	ca.0.007	<9.4x10^{-4}-<0.015	1100	2100
Bromine	5	0.005	0.002	0.005	1.3x10^{-5}-0.013	68	150
Calcium	5	0.015	0.014	0.007	0.0079-0.023	100,000	220,000
Cerium	4	0.014	0.001	0.023	<0.0001-0.048	210.	300.
Cesium	3	1.1x10^{-6}	1.1x10^{-6}	0.1x10^{-6}	0.93-1.2x10^{-6}	0.0011	0.0019
Chlorine	4	0.20	0.07	0.21	0.0083-0.40	1.7x10^{5}	2.9x10^{5}
Chromium	6	0.0015	0.0002	0.0013	6.9x10^{-7}-0.003	20.	50.
Cobalt	3	0.0035	8.3x10^{-6}	0.0061	2.3x10^{-7}-0.0105	30.	75.
Copper	3	0.0035	0.0025	0.0035	0.0014-0.0075	37.	100.
Europium	4	0.013	0.007	0.018	0.0038-0.040	3.6	5.8
Gallium	3	0.010	0.0001	0.015	3.1x10^{-8}-0.0281	37.	60.
Hafnium	4	<0.05	<0.006	ca.0.10	<0.0017-0.20	35.	51.
Iron	4	3.0x10^{-4}	1.4x10^{-4}	2.2x10^{-4}	0.085-5.3x10^{-4}	3800	8400
Lanthanum	3	4.8x10^{-4}	0.029x10^{-4}	7.2x10^{-4}	1.5x10^{-10}-0.0013	3.9	6.1
Magnesium	3	ca.0.005	ca.0.005	<0.002	>0.003-<0.007	4800.	12000.
Manganese	4	0.0055	0.0054	0.0007	0.0045->0.0059	170.	65.0
Mercury	4	0.29	0.11	0.44	0.022-0.94	37.	180
Nickel	4	<0.02	<0.01	ca.0.038	<0.002-<0.059	323	2000.
Potassium	5	0.012	0.001	0.024	6.4x10^{-5}-0.055	24000.	51000.
Rubidium	5	0.0021	0.0017	0.0015	0.00068-0.0044	50.	180.
Samarium	3	0.0026	0.0001	0.0023	9.1x10^{-8}-0.004	3.4	5.8
Scandium	5	7.x10^{-5}	0.02x10^{-5}	16x10^{-5}	7.7x10^{-9}-3.6x10^{-4}	0.20	0.34
Selenium	4	0.0027	0.0002	0.0034	4.1x10^{-6}-0.007	9.4	24.
Sodium	4	0.0027	0.0020	0.0020	0.00047-0.0051	4600.	2.4x10^{4}
Strontium	4	0.0067	0.0045	0.0045	0.00063-0.0113	680.	1400.
Tantalum	3	2.3x10^{-6}	2.3x10^{-6}	0.3x10^{-6}	2.0x10^{-6}-2.5x10^{-6}	4.7x10^{-4}	6.5x10^{-4}
Terbium	4	6.3x10^{-4}	0.04x10^{-4}	12.5x10^{-4}	3.3x10^{-7}-0.0025	0.11	0.18
Thorium	4	<5.3x10^{-4}	<5.3x10^{-4}	ca.0.4x10^{-4}	<5.0 <5.9x10^{-4}	2.0	4.3
Titanium	5	0.0029	0.0028	0.0007	0.0017-0.0038	1300.	2800.
Vanadium	4	0.0066	0.0055	0.0038	0.0017-0.011	150.	280.
Zirconium	3	0.0016	0.0016	0.0004	<0.0013 0.0020	77.	150.
All Arithmetic **means above**	34	0.020	0.002	0.059	1.1x10^{-6}-0.29		

TABLE 31. PARTITIONING FACTORS AND ESTIMATED CONCENTRATION OF INORGANICS IN SRC-I FILTER CAKE

	Partitioning Factors					Estimated Filter Cake[a] Composition	
Name	Number of Deter-mination	Arithmetic Mean	Geometric Mean	Unbiased Standard Deviation	Range	Average	Maximum
Antimony	4	2.1	1.9	0.8	0.89-2.6	4.6	10.5
Arsenic	5	2.1	2.1	0.4	1.6-2.7	23.	74.
Barium	7	2.7	2.6	0.6	1.8-3.6	675.	1350.
Bromine	6	2.3	2.1	1.3	1.4-4.7	37.	83.
Cerium	7	2.8	2.8	0.7	1.9-3.5	50.	70.
Cesium	7	3.1	3.1	0.5	2.5-3.7	3.7	6.2
Chromium	7	2.9	2.7	1.1	1.5-4.2	47.	110.
Cobalt	7	3.0	2.9	0.6	2.1-3.5	30.	75.
Europium	5	2.5	2.4	0.8	1.5-3.8	0.80	1.3
Hafnium	6	2.5	2.5	0.5	1.9-3.3	2.0	3.0
Iron	5	2.9	2.8	0.5	2.2-3.4	43000.	96000.
Lanthanum	3	1.1	0.0011	1.7	$1.5\text{x}10^{-9}$-3.00	11.	16.
Lutetium	6	2.8	2.7	0.6	1.8-3.3	0.36	0.62
Nickel	7	2.3	2.2	1.0	1.3-4.1	44.	280.
Potassium	5	2.7	1.6	1.5	0.077-3.5	6200.	13500.
Rubidium	6	3.2	3.2	0.2	2.9-3.4	90.	320.
Samarium	1	3.3	3.3		3.3-3.3	5.0	8.6
Scandium	6	2.4	2.4	0.5	1.8-2.9	8.4	14.
Selenium	8	3.0	2.9	1.0	2.3-5.3	12.	31.
Sodium	6	2.8	2.8	0.6	1.8-3.3	5600.	29000.
Strontium	5	2.1	2.1	0.5	1.5-2.8	250.	540.
Tantalum	6	2.1	2.1	0.4	1.7-2.8	0.50	0.69
Terbium	6	2.4	2.4	0.5	1.6-3.3	0.48	0.82
Thorium	7	2.8	2.7	0.5	2.2-3.2	13.	27.
Uranium	2	2.8	2.5	1.8	1.5-4.1	6.2	23.
Zirconium	6	2.5	2.4	0.5	1.8-3.3	140.	275.
All Arithmetic means above	26	2.6	2.5	0.5	1.1-3.3		
All Maximum above	26	3.5	3.4	0.6	2.6-5.3		

[a] Filter cake part of SRC-I only

TABLE 32. PARTITIONING FACTORS AND ESTIMATED CONCENTRATION OF TRACE ELEMENTS IN SRC SULFUR BY-PRODUCTS

Name	Partitioning Factor[a]	Estimated Sulfur Composition (ppm) Average	Maximum
Aluminum	$<5.1\times10^{-4}$	<6.8	< 9.4
Antimony	<0.1	<0.2	< 0.5
Arsenic	<0.16	<1.7	< 5.6
Barium	<0.73	<180.	< 365.
Bromine	<0.66	<11.	< 24.
Calcium	<1.8	<14000.	< 31000.
Cerium	<0.096	<1.7	< 2.4
Cesium	0.26	0.31	0.52
Chlorine	<0.15	<150.	< 250.
Chromium	0.15	2.4	5.9
Cobalt	18.7	190	470
Copper	<0.05	<0.64	< 1.7
Europium	<0.04	<0.013	< 0.021
Gallium	<0.42	<1.8	< 2.9
Hafnium	<0.39	<0.32	< 0.47
Iron	<0.05	<740.	< 1650
Lanthanum	0.238	2.3	< 3.6
Magnesium	<0.26	<290.	< 730.
Manganese	<0.24	<8.6	< 33.
Mercury	1.4	0.21	1.0
Praseodymium	0.12		
Ruthenium	ca. 2.		
Samarium	0.23	0.35	0.60
Scandium	<0.008	<0.028	< 0.047
Selenium	<0.75	<3.0	< 7.8
Sodium	22.8	46000.	2.3×10^{5}
Strontium	<0.51	<61.	< 130.
Tantalum	1.4	0.34	0.46
Terbium	<0.26	<0.052	< 0.088
Thorium	<0.1	<0.45	< 0.97
Titanium	<0.17	<90.	< 190.
Vanadium	0.27	7.0	14.
Zirconium	<0.97	<55.	< 110.

Only one estimate available:

Arithmetic mean of all partitioning factors: 1.7
Geometric mean of all partitioning factors: 0.3
Unbiased arithmetic standard deviation: 5.0
Range of all partitioning factors: 0.00051-22.8

TABLE 33. ELEMENT CONCENTRATIONS IN PROCESS STREAMS AS DETECTED BY SPARK SOURCE MASS SPECTROSCOPY (ppm)*

	Raw coal	Naphtha	Middle distillates	Heavy distillates	Residue
Aluminum	>1(0.48%)	1.4	0.18	23	1
Antimony	0.56(38)			0.003	0.37
Arsenic	0.59			0.006	3.6
Barium	40(26)	0.004		0.050	140
Beryllium	0.60			0.003	3.2
Bismuth	0.42			0.008	0.19
Boron	130	0.009	0.012	1.2	1000
Bromine	0.61			0.006	4.0
Cadmium	(**)		0.001	0.024	0.23
Calcium	>0.5%(0.16%)	0.080	0.057	5.9	1%
Cerium	17			0.010	10
Cesium				0.001	1.2
Chlorine	210	0.004	0.004	0.21	28
Chromium	5.8(7)	0.003	0.001	2.5	29
Cobalt	6.0		0.001	0.011	3.6
Copper	30(8.5)	0.004	0.042	0.100	17
Dysprosium	0.84			0.004	0.52
Erbium	0.98			0.012	0.66
Europium	0.24			0.005	0.20
Fluorine	90	0.003	0.003	0.34	260
Gadolinium	0.43			0.008	0.90
Gallium	2.2			0.003	2.9
Germanium	1.0			0.003	4.6
Hafnium	0.45	0.002	0.002	0.018	0.60
Halmium	0.32			0.002	0.113
Iodine				0.005	0.95
Iron	>1%(0.1%)	0.034	0.23	62.0	1%
Lanthanum	8.0			0.009	3.7
Lead	4.3		0.002	0.007	6.2
Lithium	0.60			0.017	67
Lutecium	0.12			0.002	
Magnesium	1000(768)	4.2	0.063	2.1	1200
Manganese	73.0(34)		0.002	0.79	87
Molybdenum	8.3	0.004	0.002	0.016	3.7
Neodymium	7.4			0.012	3.6
Nickel	7.5(11)		0.002	0.16	18
Niobium	2.6			0.002	2.1
Phosphorus	35	0.053	0.025	2.5	1400
Potassium	1900(1243+)	0.034	0.068	6.8	1900
Praseodymium	7.3			0.003	1.9
Rubidium	18			0.016	53
Samarium	1.4	0.002	0.002	0.021	0.58
Scandium	1.3			0.006	3.8

(continued)

TABLE 33. (continued)

	Raw coal	Naphtha	Middle distillates	Heavy distillates	Residue
Selenium	0.58(41+,++)		0.003	0.003	3.1
Silicon	1%	0.53	0.60	100	1%
Silver					0.08
Sodium	550(311+)	0.16	0.053	8.0	500
Strontium	38			0.023	56
Sulfur	1%		0.053	1.6	0.5%
Tantalum				0.003	0.17
Thallium	0.43			0.007	1.3
Thorium	3.0			0.006	4.0
Tellurium	0.15(**,++)				
Terbium				0.002	0.10
Thullium	0.24			0.003	0.22
Tin	0.25(0.4++)			0.15	1.9
Titanium	520		0.004	0.68	760
Tungsten	0.25			0.011	0.52
Uranium	4.0			0.007	3.4
Vanadium	30.0(1.5++)	0.001		0.13	70
Ytterbium	0.61				0.30
Yttrium	10			0.007	4.1
Zinc	5.3(16)	0.001	0.21	0.10	40
Zirconium	11			0.018	17

* Concentrations detected by atomic absorption in raw coal are indicated in parentheses.
**Indicates concentrations below instrument detection limits.
+ Detection by flame emission.
++Detection by graphite furnace.

NOTE: Figures for elements for which values are not entered:

Raw coal	< 0.001 ppm
Middle distillates	< 0.001 ppm
Heavy distillates	< 0.001 ppm
Residue	< 0.05 ppm

The accuracy of spark source analysis is generally ± 100 to 500 percent. HAI data suggest for the most trace elements the desired accuracy for a Level 1 analysis (i.e., within a factor of 2 to 3) is achieved.

3.4.1.4 Additional SRC-I and SRC-II Analysis

Battelle's inorganic studies of the solid product mode show that except for mercury, titanium, and bromine, most elements appear to remain with the mineral residue. For bromine, approximately 84 percent remains with the product, whereas for titanium, approximately 56 percent remains with the product. In the case of mercury, 89 percent is unaccounted for in the solid and liquid products and is presumably emitted in the process off-gas.

A comparison between liquid samples derived from SRC-I solid and SRC-II liquid process modes is presented in Battelle's inorganic analysis data, Table 34.

3.4.2 Organic Analysis

3.4.2.1 SRC-II Level 1 Methodology and SAM/IA Analysis

The diversity of organic compounds which can comprise the product streams from a liquefaction system preclude complete identification without years of research. It has been estimated that only 10 percent of the possible compounds in hydrogenation products have been identified and that those compounds found in the MEG's represent even a smaller percentage.

TABLE 34. INORGANIC ELEMENT CONTENT OF LIQUID SAMPLES FROM COAL LIQUEFACTION - REFINED SOLID (51)

	Light Oil (Naphtha) (Solid Product Process)		Process Solvent (Solid Product Process)		Light Oil Naphtha (Liquid Product Process)	Heavy Oil (Liquid Product)
	INAA *	XRF **	INAA	XRF	XRF	XRF
Na	1.7±0.3		0.51±0.1			
S					1600±500	3650±700
Cl		< 36				
K		< 3		< 67	< 55	< 55
Ca		< 3			< 34	102±17
Ti	1.8±.7	2.2±.15		9.3±3.1	< 0.5	36±5
V		< .6		3.2	< 6	12±3
Cr	0.044±.009	< .2	0.54±.02	10.5±1.5	< 3	6.3±1.8
Mn		0.21±.06		< 1.11	< 1.8	< 1.1
Fe	1.1±.3	< 2	58±2	102±7	< 1.6	660±45
Co	0.0026±.0005		0.0044±.0001			
Ni	< .10	< .05		1.35±.2	< .63	5.0±.5
Cu		< .07		< .4	< .71	0.80±.30
Zn	0.58±.04	0.46±.07	0.86±.04	0.54±.14	< 1.68±.35	1.9±.2
As	0.013±.001	0.01±.02	0.105±.002	< .23	< .38	0.34±.13
Se	0.065±.020	0.086±.030	< .009	< .15	0.60±.20	0.31±.10
Br	0.018±.002	< .07	0.25±.01	0.29±.05	< .61	< .26
Rb	.05		< .06	< .26	< .61	< .26
Sr		< 1.1		< 2.4	< 5	< 2.4
Sb	< .002		0.006±.09			
Ba	< 1		< 2			
La	< .001		0.0125±.008			
Hf	< .003		< .003			
Hg	0.05±.01		.01			
Pb		< 1	< .001	< 1.7	< 1.7	< .16
Th	< .0009					

*Instrumental neutron activation analysis
**X-Ray Flourescence

Hittman Associates' Level 1 analysis of the SRC-II product streams was intended to show relative distribution of broad classes of compounds and to determine for the middle and heavy distillates, quantitative estimates for organics present in highest concentrations.

3.4.2.2 Comparison of Product Streams

3.4.2.2.1 Naphtha

Infrared analysis on the naphtha stream suggests that aliphatics are the main compound type present, as indicated by the carbon-hydrogen stretch at 2900 cm^{-1} and 2850 cm^{-1}. Considerable branching is evident. However, the presence of phenols and substituted benzenes is also evident. A weak band is observed at 3300 to 3400 cm^{-1} and at 1240 cm^{-1} suggesting the presence of phenols. Several peaks in the region of 700-800 cm^{-1} indicate the presence of substituted benzenes.

3.4.2.3 SRC-I

In conducting organic analysis of SRC samples, Battelle Northwest utilized a separation scheme which partitions the sample into four fractions: basic, acidic, neutral and PAH. The fractions were then analyzed by gas chromatography and gas chromatography-mass spectrometry (GC/MS).

The SRC-I data presented in Table 35 are for the two major fractions: PAH and neutral. The concentration of low molecular weight members of both fractions are misleading because their loss in the partitioning scheme has not been corrected in this table. The light oil, wash solvent and process solvent are three distillate cuts; the raw process

TABLE 35. ANALYSIS OF SRC-I ORGANICS FOR PAH AND NEUTRAL FRACTIONS (IN PPM) (51)

PNA Fraction	Light Oil	Wash Solvent	Process Solvent	Raw Process Water	Mineral Residue	Solvent Refined Coal	Particulate Filter Concentration ug/m^3
Xylene		1300					
o-ethylbenzene	9800	1700					
m/p-ethylbenzene		700					
C_3-benzene	3900	1500					
C_4-benzene		500					
indane	4300	13000			85		
methlindane	510	2500		15	25		
methylindane	180	1400					
methylindane	240	2300			55		
dimethylindane	5	40			25		
tetralin	330	4100		0.1	110		
dimethylteralin	5	1500		0.5	35		
6-methyltetralin	110	3200			50		
naphthalene	1630	32000	100	5	1500		
2-methylnaphthalene	690	32000	3800	2	740	8	15
1-methylnaphthalene	110	12000	930		180	5	15
dimethylnaphthalene	80	13000	11200	0.3	260	6	170
dimethylnapthalene	70	700	1700		60		20
dimethylnaphthalene		4000	4200		150		
dimethylnaphthalene	10	160	650	2	2		10
2-isopropylnaphthalene		40	50	0.7	1		0.5
1-isopropylnaphthalene		210	1400	2	15		20
C_4-naphthalene		5	50		1		4
cyclohexylbenzene		410			5		
biphenyl	80	10000	5900	0.2	270	2	75
acenaphtylene	2	500	3400	0.1	45	8	60
dimethylbiphenyl	15	35	2100	0.5	30	9	130
dimethylbiphenyl	21	30	550	0.2	20	7	40
dibenzofuran	8	400	5800	0.6	60	9	150
xanthene	10	30	840	0.1	20	5	40
dibenzothiophene	3	50	4200	1.5	70	30	180
methyldibenzothiophene		15	320	0.1	8	4	60
dimethyldibenzothiophene	5	15	1200	0.05	20	13	130
thioxanthene		2	3300	0.1	5	3	120
fluorene	15	250	6600	0.3	80	27	200
9-methylfluorene	15	110	3100	0.3	40	11	153
1-methylfluorene	10	10	3000	0.2	50	18	100
antrhacene/phenanthrene	25	130	23000	1.1	500	300	1500
methylphenanthrene	6	15	6200	0.3	100	50	400
1-methylphenanthrene	6		3900	0.2	50	30	300
C_2-anthracene	6	25	500	0.05	10	1	30
fluoranthene	15	35	10500	0.4	200	180	700
dihydropyrene	6	25	1200	0.05	10	1	30
pyrene	20	40	11200	0.6	200	280	900
NEUTRAL FRACTION (n-alkanes)							
n-octane	1600	900		2.3			
n-nonane	8700	2700					
n-decane	9800	5000					
n-undecane	3900	8300	50	0.3	90	4	
n-dodecane	1400	21000	80	0.3	550	10	
n-tridecane	470	14000	340	0.4	9100	8	4
n-tetradecane	170	1100	340	0.3	210	7	12
n-pentadecane	60	4000	1000	0.2	80	12	18
n-hexadecane	10	400	2000	0.2	50	8	50
n-heptadecane	10	120	3100	0.02	20	3	35
n-octadecane		40	920		10	3	18
n-nonadecane		500	800		16	22	30
n-eicosane			930		14		20
n-heneicosane			600		14		35
n-docosane			670		16		55
n-tricosane			980		14		35
n-tetracosane			900		14		45
n-pentacosane			740		10		43
n-hexacosane			450		8	5	40
n-heptacosane			300		6	2	25
n-octacosane			150		5	2	28
n-nonacosane			90		4	1	18
n-triacontane			60		2	1	22
n-hentriacontane			40		1	1	15
n-dotriacontane			10		1		11
n-tritriacontane			5				7

*The concentration of low molecular weight members of both fractions are misleading because their loss in the partitioning scheme has not been corrected in this table.

water, mineral residue, solvent refined coal and particulate filter were extracted before analysis. The particulate filter sample was collected directly over the cooling product before any inline devices for aerosol control.

The gases evolved from the process are separated from the slurry as the slurry is depressurized. In a commercial plant these gases, after cleanup, would supply process heat, but in the pilot operation after removal of the acid gases, the mixture is flared. The major organic components of these gases consist of aliphatic compounds, both straight and branched members, methylated cyclohexanes, benzene, toluene, xylenes, C_3-benzenes. Battelle has also tentatively identified carbon disulfide and pyrrolidine in the gases.

3.5 Waste Streams to Air

The SRC process is, for the most part, an enclosed and pressurized system. Consequently, air emissions during regular plant operations arise primarily from auxiliary parts of the system, such as the cooling towers, boilers, acid gas treatment, and sulfur recovery process. Process related emissions should be limited to leaks in pump seals, valves, joints, and flanges and from product handling and storage.

The following subsections describe emissions to air (except for process flue gases, summarized in Table 36. "After treatment" characterizations are based on application of control methods suggested in Section 4.0.

TABLE 36. FLUE GASES FROM AUXILIARY PROCESSES (6)

Module	Total Mg/day	Nitrogen,Oxygen Mg/day	Water Vapor Mg/day	Carbon Dioxide Mg/day
Coal pretreatment	3590	2870	225	500
Hydrogenation	13400.	10700.	844	1870
Solids separation	9780.	7800.	616	1363.
Fractionation	2080.	1660.	131.	290.
Hydrotreating	1540	1230.	97.	215
Hydrogen production	1020	809.	64.	142
Sulfur recovery[a]	157	122.	10.	21.
Steam and power generation[b]	11900	9090.	410	2320.

[a] Also produces 4.0 mg/day ash (1.40×10^{-4} X input coal).

[b] Also produces 37 mg/day ash, 64 mg/day sulfur dioxide, 8. mg/day nitrogen oxides, 0.5 mg/day carbon dioxide, 0.2 mg/day hydrocarbons (as ethane) and a total flow rate of 10.6 m^3/sec.

3.5.1 Coal Pretreatment

Coal dust is generated during the transfer of coal from shipping to receiving bins and during coal storage, conveying, stacking, and sizing. Dust is composed of coal particles, typically from 1 to 100 microns in size, with a composition similar to the parent coal. It is estimated that 23 Mg/day of particulates will be generated from coal receiving, storage, and sizing and 29 Mg/day of particulates will be emitted with dryer stack gas (6). By applying known removal efficiencies for particulates estimates of emissions after control have been determined.

3.5.1.1 Dust From Coal Sizing

Coal dust generated from coal sizing has been estimated at 7.4 Mg/day without controls (6). Assuming four units, each handling 1.9 m^3/sec with a loading of 11.12 grams/m^3 (8,646 ppm), emissions after treatment are estimated as follows:

Treatment	Efficiency of Removal	Emissions after Treatment (ppm)	Emissions after Treatment (mg/m^3)
cyclone + baghouse	99.9%	8.6	11
wet scrubber	98.5%	129.7	167

3.5.1.2 Dust from Coal Storage

The problem of controlling dust emissions from coal storage is a formidable one. Polymer spraying is recommended to reduce dust emissions. Dust emissions following polymer spraying have not been estimated.

3.5.1.3 Dryer Stack Gas

Particulate emissions from dryer stack gas are estimated at 29 Mg/day without controls. This assumes that the flow dryer is equipped with a cyclone collector built within the unit.

Assuming 378 m^3/sec gas flow (6) at 60°C with a loading of 0.9 grams/m^3 (712 ppm) the estimated emissions with control technology are as follows:

Treatment	Efficiency	Emission After Treatment, ppm (mg/m^3)
cyclone	80% (20)	142 ppm (183)
baghouse	99.9%	0.7 ppm (0.9)
wet scrubber	98.5%	10.7 ppm (13.5)

3.5.1.4 Trace Element Composition of Coal Particulates from Coal Pretreatment

The trace element distribution in coal particulates is somewhat a function of particle size. This factor complicates our efforts to estimate the trace element makeup on a stream containing particulates. Table 37 is a first approximation of the trace element makeup in treated dust streams from the coal pretreatment module, including coal receiving, crushing and drying. The minimum value listed in this table refers to the concentration of elements in the dust stream emanating from the most effective dust control device (a cyclone with baghouse), and the maximum refers to the dust emitted from the least effective control device (a wet scrubber). This approximation assumes that trace elements are evenly distri-

TABLE 37. ESTIMATE OF INORGANIC COMPOSITION OF ATMOSPHERIC EMISSION AFTER CONTROL OF COAL DUST FROM COAL PRETREATMENT MODULE

Name	Based on "Average U.S. Coal" Concentration ($\mu g/m^3$)		Based on "Maximum U.S. Coal" Concentration ($\mu g/m^3$)	
	Min.	Max.	Min.	Max.
Aluminum	12.	8000.	16.	11000.
Antimony	0.0019	1.3	0.0044	2.9
Arsenic	0.010	6.4	0.032	21.
Barium	0.22	146.	0.45	290.
Beryllium	0.0013	0.84	0.0027	1.7
Boron	0.049	33.	0.11	70.
Bromine	0.014	9.8	0.032	22
Cadmium	0.0030	2.0	0.015	9.8
Cerium	0.016	10.	0.022	15.
Cesium	0.0011	0.70	0.0017	1.2
Chlorine	0.91	590.	1.5	980
Chromium	0.015	9.8	0.035	23.
Cobalt	0.0092	6.1	0.022	15.
Copper	0.011	7.7	0.030	20.
Dysprosium	0.0012	0.78	0.0021	1.4
Europium	2.9×10^{-4}	0.19	4.6×10^{-4}	0.31
Fluorine	0.070	46	0.14	98.
Gallium	0.0040	2.6	0.0063	4.1
Germanium	0.0056	3.7	0.013	8.4
Hafnium	7.3×10^{-4}	0.49	0.0011	0.70
Indium	1.5×10^{-4}	0.098	2.1×10^{-4}	0.14
Iodine	0.0012	0.77	0.0015	0.98
Iron	13.	9100.	30.	20000.
Lanthanum	0.0046	3.0	0.0086	5.7
Lead	0.012	7.7	0.059	38.
Lithium	0.0318	21	0.070	46.
Lutetium	1.2×10^{-4}	0.077	1.9×10^{-4}	0.13
Magnesium	1.0	660.	2.5	1700.
Manganese	0.032	22	0.12	82.
Mercury	1.3×10^{-4}	0.091	6.5×10^{-4}	0.43
Molybdenum	0.0046	3.1	0.011	7.0
Nickel	0.017	11.	0.11	70.
Niobium	<0.0016	<1.0	<0.0017	<1.2
Phosphorus	0.094	61	0.14	89.
Potassium	2.1	1400	4.5	2900.
Rubidium	0.025	17	0.091	59.
Samarium	20.0014	0.91	0.0024	1.5
Scandium	0.0038	2.1	0.0052	3.5
Selenium	0.0037	2.7	0.0094	6.1

(continued)

TABLE 37. (continued)

Name	Based on "Average U.S. Coal" Concentration ($\mu g/m^3$)		Based on "Maximum U.S. Coal" Concentration ($\mu g/m^3$)	
	Min.	Max.	Min.	Max.
Silicon	21.	13000	25	16000
Silver	1.5×10^{-4}	0.098	6.4×10^{-4}	0.41
Sodium	1.7	1200	9.2	6100.
Strontium	0.11	70.	0.23	150.
Sulfur	19.	13000.	32.	22000.
Tantalum	2.2×10^{-4}	0.14	3.0×10^{-4}	0.20
Tellurium	2.2×10^{-5}	0.015	2.7×10^{-5}	0.017
Terbium	1.7×10^{-4}	0.12	3.0×10^{-4}	0.20
Thallium	5.9×10^{-4}	0.39	5.9×10^{-4}	0.39
Thorium	0.0040	2.7	0.0087	5.7
Tin	0.0017	1.2	0.0045	2.9
Titanium	0.48	3.10	1.0	670
Tungsten	6.4×10^{-4}	0.43	7.3×10^{-4}	0.49
Uranium	0.0019	1.3	0.0073	4.8
Vanadium	0.024	15	0.044	29.
Ytterbium	5.7×10^{-4}	0.38	7.5×10^{-4}	0.50
Zinc	0.11	70.	1.3	865.
Zirconium	0.051	33.	0.099	65

buted in dust particles independent of particle size. In an analysis of the trace element composition in different particle sizes of coal dust from a Pittsburgh seam coal, 27 trace elements were found to be evenly distributed independent of particle size, while 11 trace elements were distributed in concentrations that varied with particle size (57).

3.5.2 Coal Liquefaction

The waste streams to air of the coal liquefaction module will consist primarily of fugitive (hydrocarbon) emissions. The fugitive emissions cannot be quantified at this time.

3.5.3 Separation

3.5.3.1 Gas Separation Process

As in the coal liquefaction module, the waste streams to air from the gas separation module will consist primarily of fugitive (hydrocarbon) emissions which cannot be quantified at this time.

3.5.3.2 Solids/Liquids Separation Process

The waste streams to air from the solids/liquids separation module will consist primarily of fugitive (hydrocarbon) emissions and flue gases. The flue gases will be discussed later; quantification of fugitive emissions is not possible at this time.

3.5.4 Purification and Upgrading

3.5.4.1 Fractionation Process

The waste streams to air from the fractionation module will consist primarily of fugitive (hydrocarbon) emissions and flue gases. The fugitive emissions cannot be quantified at this time.

3.5.4.2 Hydrotreating Process

As in solids/liquids separation the waste streams to air from the hydrotreating module will consist primarily of fuigitive (hydrocarbon) emissions and flue gases. The fugitive emissions cannot be quantified, the flue gases are combined and treated by the auxiliary processes, and will be discussed subsequently.

3.5.5 Auxiliary Processes

3.5.5.1 Receiving and Storage

Before treatment the emissions amount to approximately 7.3 Mg/day (6). Assuming a gas stream flow of 1.9 m^3/sec with a loading of 44.6 grams/m^3 (34,689 ppm) and maximum removal efficiencies for the treatment equipment, emissions after treatment are estimated as follows:

Treatment	Efficiency	Emissions After Treatment (mg/m^3)
cyclone + baghouse	99.9%	35 ppm (44.7)
wet scrubber	98.5	520 ppm (669)

3.5.5.2 Water Supply

No estimates are available on dust emissions from lime storage. These emissions are more likely to be a nuisance than a serious health hazard.

3.5.5.3 Water Cooling

There are currently no emission standards for cooling towers. In view of the large quantities of evaporation and drift (22,448 Mg/day) (6) these losses warrant environmental concern. The cooling tower will also require 23,000 Mg makeup water per day.

Tower evaporative losses having undergone distillation, should be quite free of dissolved solids. Thus, impact will be limited to the effect of excess water vapor in the air near the plant.

Cooling tower drift results from water droplets mechanically generated in the tower. The composition can be expected to be similar to the tower circulating water. This could result in contamination from dissolved minerals and corrosion inhibitors. The actual composition of drift depends upon the number of circulations as a multiple of the river salinity. This is somewhat complicated by the fact that a blowdown from steam generation will be used in cooling tower makeup. In addition, an unidentified quantity of the corrosion inhibitors and antifouling agents are lost in drift.

3.5.5.4 Steam and Power Generation

The steam generation module advocated in the Standards of Practice Manual utilizes coal-fired boilers. A total of approximately 930 Mg/day of coal are required to generate the necessary steam. Particulates in the stack gas from steam generation have been estimated at 3.69×10^6 μg/m^3. Particulates in the stack gas are recovered as fly ash and can be a potential source of emissions if not handled properly. This will be considered as a solid waste problem. In order to meet standards such as Illinois emission standards, particulates from coal-fired boilers must be removed with an efficiency of 98.65 percent. Elbair scrubbers and venturi scrubbers are capable of removal up to 99 percent of the particulates in fly ash. Medium energy venturi scrubbers will remove almost 100 percent of particulates $<$50 microns, 99 percent of particules $<$5 microns, and 97 percent of particulates $<$1 micron.

Organic compounds may reach the environment by being sorbed on the fly ash during combustion and subsequent volatilization. Since the concentration of the organics introduced into the environment by this mechanism will be considerably less than in the gaseous emission streams, and since the organics in the emission streams are not toxic (they may be asphyxiants), the only organics which are likely to cause any environmental harm are the carcinogenic polynuclear aromatic hydrocarbons (PAH).

The ash residue resulting from the combustion of coal is primarily derived from the inorganic mineral matter in the coal. Generally, ash makes up from three to 30 percent of the coal (58).

During the combustion of coal, the products formed are partitioned into three categories: bottom ash, fly ash, and gases. The bottom ash is that part of the residue which is fused into particles heavy enough to drop out of the furnace gas stream (air and combustion gases). These particles are collected in the bottom of the furnace. The fly ash is that part of the ash which is entrained in the combustion gas leaving the boiler. While most of this fly ash is collected in either mechanical collectors and/or electrostatic precipitators, a small quantity of this material passes through the collectors and is discharged into the atmosphere. The gas is that part of the coal material which is volatilized during combustion. Some of these gases are discharged into the atmosphere; others condense onto the surface of fly ash particles and may be collected in one of the fly ash collectors. For the majority of elements found in coal, most of their quantity (95 percent or more) will be found in the ash fractions, while the remainder (5 percent or less) will be discharged into the atmosphere. The quantity of vapors produced depends primarily on the temperature history of the combustion gases and the concentrations and properties of the various elements in the coal (58).

The distribution of the ash between the bottom ash and fly ash fractions is a function of the burner type, the type of coal (ash fusion temperature), and the type of boiler bottom (wet or dry). The first factor, burner type, is especially significant in determining the distribution. The second factor, ash fusion temperature, is important in that ashes with lower fusion temperatures tend to be melted within the boiler and collected as bottom ash. Finally, wet bottom boilers are designed to produce and process a much larger proportion of bottom ash than dry bottom boilers (58).

The ash particles vary from less than 1 micron to 4 cm in diameter. The fly ash fraction generally consists of fine spherical particulates usually ranging in diameter from 0.5 micron to 100 microns. The pH of fly ash contacted with water may vary from 3 to 12, with the pH for the majority of pulverized coal-burned fly ashes contacted with water ranging from 8 to 12 (58).

Table 38 presents the average composition of fly ash from six domestic power plants (58). The concentration of trace elements in the fly ash depends on the particle size. Generally, increasing concentrations are correlated with decreasing particle size (see Table 39). There is a definite enrichment of certain elements in the smallest particles emitted from a power plant. These elements include lead, thallium, antimony, cadmium, selenium, arsenic, nickel, chromium, zinc and sulfur. The highest concentrations of the trace constituents occur in particulates in the 0.5 to 10.0 micron diameter range.

Table 40 presents the concentrations of coal and fly ash at different locations in the United States. This table also presents enrichment factors which can be used to estimate the elemental composition of any fly ash, provided the elemental composition of the burned coal is known. The enrichment factor is defined as the concentration in the fly ash divided by the concentration in the coal. In this report, the enrichment factors are used to estimate the average and maximum elemental concentrations in all fly ash found in the United States. Table 41 shows enrichment factors for averaged analysis of National Bureau of Standards coal and fly ashes (59) and for three power stations using unidentified coals (60).

TABLE 38. COMPOSITION OF FLY ASHES FROM DIFFERENT (UNSPECIFIED) LOCATIONS ACROSS THE UNITED STATES (58)

Compound or Element	Number of Determinations	Arithmetic Mean	Geometric Mean	Unbiased Standard Deviation	Range
SiO_2 (%)	5	51.	50.	8.	42.-59.
Al_2O_3 (%)	5	23.	22.	5.	17.-28.
Fe_2O_3 (%)	6	9.	7.	7.	3.8-20.4
CaO (%)	6	6.	5.	5.	3.2-17.
SO_3 (%)	4	0.8	0.7	0.6	0.4-1.7
MgO (%)	5	1.5	1.4	0.5	0.96-2.23
Na_2O (%)	5	1.3	1.2	0.6	0.38-1.88
K_2O (%)	5	1.3	1.1	0.8	0.4-2.4
P_2O_5 (%)	4	0.5	0.2	0.5	0.04-1.00
TiO_2 (%)	5	0.9	0.9	0.3	0.43-1.17
Arsenic (ppm)	6	27.	14.	41.	6.-110.
Beryllium (ppm)	5	6.	6.	2.	3.-8.
Boron (ppm)	4	366.	325.	226.	200.-700.
Cadmiun (ppm)	6	3.	1.	3.	0.5-8.0
Chromiun (ppm)	6	126.	81.	112.	20.-300.
Cobalt (ppm)	6	17.	14.	12.	6.-39.
Copper (ppm)	6	89.	84.	36.	54.-140.
Fluorine (ppm)	5	345.	266.	255.	100.-624
Lead (ppm)	6	52.	47.	24.	30.-80.
Manganese (ppm)	6	202.	188.	79.	100.-298.
Mercury (ppm)	6	3.	0.1	8.	0.01-20.
Nickel (ppm)	6	82.	52.	76.	10.-207.
Selenium (ppm)	6	16.	14.	8.	6.9-26.5
Vanadium (ppm)	6	212.	177.	144.	90.-440.
Zinc (ppm)	6	230.	135.	274.	50.-740.

TABLE 39. CONCENTRATIONS AND CONCENTRATION TRENDS WITH DECREASING FLY ASH PARTICLE SIZE FOR SELECTED ELEMENTS (58)

Particle diam. (microns)	Pb (ppm)	Tl (ppm)	Sb (ppm)	Cd (ppm)	Se (ppm)	As (ppm)	Ni (ppm)	Cr (ppm)	Zn (ppm)	S (wt %)	Percent of Particles in This Size Category
Fly Ash Retained in Plant											
A. Sieved Fractions											
74	140	7	1.5	10	12	180	100	100	500	...	66.30
44-74	160	9	7	10	20	500	140	90	411	1.3	22.89
B. Aerodynamically Sized Fractions											
40	90	5	8	10	15	120	300	70	730	0.01	2.50
30-40	300	5	9	10	15	160	130	140	570	0.01	3.54
20-30	430	9	8	10	15	200	160	150	480	...	3.25
15-20	520	12	19	10	30	300	200	170	720	...	0.80
10-15	430	15	12	10	30	400	210	170	770	4.4	0.31
5-10	820	20	25	10	50	800	230	160	1100	7.8	0.33
5	980	45	31	10	50	370	260	130	1400	...	0.08

Particle diam. (microns)	Fe (wt %)	Mn (ppm)	V (ppm)	Si (wt %)	Mg (wt %)	C (wt %)	Be (ppm)	Al (wt %)
Fly Ash Retained in Plant								
A. Sieved Fractions								
74	...	700	150	...	...	...	12	...
44-74	18	600	260	18	0.39	11	12	9.4
B. Aerodynamically Sized Fractions								
40	50	150	250	3.0	0.02	0.12	7.5	1.3
30-40	18	630	190	14	0.31	0.21	18	6.9
20-30	...	270	340	...	...	0.63	21	...
15-20	...	210	320	...	...	2.5	22	...
10-15	6.6	160	320	19	0.16	6.6	22	9.8
5-10	8.6	210	330	26	0.39	5.5	24	13
5	...	180	320	...	...	...	24	...

TABLE 40. CONCENTRATION OF TRACE ELEMENTS IN COAL AND FLY ASH IN DIFFERENT GEOGRAPHICAL LOCATIONS (58)

	Eastern Interior (IL, IN, Western KY)			Southwestern (AZ, NM, CO, UT)			Eastern KY, Southern IL [mean (range)]		
Name	Coal	Fly Ash	Enrichment Factor^a	Coal	Fly Ash	Enrichment Factor^a	Coal	Fly Ash	Enrichment Factor^a
Aluminum							11000 (10500-13000)	67000 (57000-74000)	5.9(5.4-6.5)
Americium							11000 (10500-13000)	67000 (57000-74000)	
Antimony	0.5	12	24		14		<1	<10	
Arsenic	14	120	8.6		130		8.8(3.8-1.8)	141(27-349)	12.4(5.7-19.4)
Barium	59	450	7.6				120(100-150)	1700(300-3000)	16(2-30)
Beryllium	<5	3-17					0.3 (<5)	3 (15-17)	10
Bismuth							<10	2	
Boron	100-200	250-3000	2.5-15				166(100-200)	1750(250-300)	9.2(2.5-15.)
Bromine							2.3(2.0-2.6)	<2-5	<2
Cadmium	6 (0.46)	160 (8.0)	26.7(17.4)						
Calcium							4200(3600-5100)	17200(14000-22000)	4.2(3.7-4.4)
Cesium							1.5(1.5-1.5)	18(15-21)	12(10-14)
Chlorine	355-407	<5-50	<0.01-0.14				407	50	0.12
Chromium	20 (20)	310(500)	15.5-25				82(30-150)	160(70-250)	2.4(1.1-3.8)
Cobalt	0 (3.0)	60 (41)	13.7				3.9(3.3-5)	37(25-51)	9.3(7.6-10.2)
Copper	20(50-100)	100(300-400)	5(3-8)	9.6	280	29.2	67(50-100)	367(300-400)	6(4-8)
Europium							0.24(0.17-0.31)	1.7(1.6-1.8)	7.9(5.2-10.6)
Fluorine	<2-60	<10-100	ca. 1.7						
Gallium							13	70	5.4
Germanium							10(5-15)	135(70-200)	14(13-14)
Iron							15800 (13000-20000)	100000 (93000-139000)	6.9(6.5-7.2)
Lanthanum							5.3(4.8-6.)	33(30-36)	6.2(6.-6.4)
Lead	<30(4.9)	200(80)	(16.3)		110		ca. 20	210(80-250)	ca. 10
Lithium							50(25-100)	280(200-350)	8.6(2-12)
Magnesium							1600(1500-1700)	8600(5500-11600)	5.3(3.2-6.8)
Manganese	90(34)	500(290)	5.6(8.5)				53(51-54)	321(316-325)	6.1(6.0-6.2)
Mercury	<2(0.122)	<0.2(0.05)	ca 0.1(0.4)				0.10(0.063-0.170)	0.06(0.04-0.10)	0.63(0.58-0.68)
Molybdenum	3.6	118	32.8	0.99	54	54.5	17(10-20)	350(150-700)	8.2(7-10)

(continued)

TABLE 40. (continued)

Name	Eastern Interior (IL, IN, Western KY)			Southwestern (AZ, NM, CO, UT)			Eastern KY, Southern IL [mean (range)]		
	Coal	Fly Ash	Enrichment Factor[a]	Coal	Fly Ash	Enrichment Factor[a]	Coal	Fly Ash	Enrichment Factor[a]
Nickel	90(<100-150)	500(500-1000	5.6(>3.3)				ca. 100	666(500-1000)	ca. 5-7
Niobium							< 15	10(6-15)	
Phosphorous							50	500	10
Potassium							2200(2000-2500)	16000(11700-19700)	7.1(5.8-7.9)
Rubidium							86(17-200)	380(200-650)	9.8(1.5-16.25)
Selenium	2.2	25	11.4	1.9	73	38.4	3.0(2.6-3.2)	24(23-24)	8.2(7.5-8.4)
Silicon							50000	300000	6
Silver							<2-5	<3-5	
Sodium							700(690-720)	6400(5800-7000)	9.2(8.0-10.3)
Strontium							200	300	1.5
Tantalum							0.1	1.2	12
Tellurium	1-3	<1-10	<10				2(1-3)	<1-ca. 10	
Thallium	2	40-100	20-50				<2	70(40-100)	
Thorium							2.7(2.4-3)	20(18-23)	7.8(6.-9.6)
Tin							20	20	
Titanium	510	6080	11.9				640(500-710)	3480(1500-5000)	5.6(2.5-7.2)
Tungsten							1	5	5
Uranium							2.7(1.67-3.3)	18(15-21)	7.2(5.0-10.2)
Vanadium	28.5	440	15.4				34(12-69)	307(100-780)	9.1(4.0-11.7)
Zinc	1100(46)	5900(740)	5.4(16.1)	7.3	360	49.3	170(85-250)	2200(500-3000)	23.6(12.0-35.3)
Zirconium							40	100	2.5

[a] Conc. in fly ash/conc. in corresponding coal.

TABLE 41. ENRICHMENT FACTORS FOR FLY ASH/COAL FROM UNSPECIFIED GEOGRAPHICAL LOCATIONS (59,60)

	NBS* Coal and Fly Ash					
Name	Enrichment Factors	Number of Coal Samples Analyzed	Number of Fly Ash Samples Analyzed	Station 1	Station 2	Station 3
Antimony	1.97	10	10	2.32	4.4	3.04
Arsenic	7.0	5	4	12.3	8.5	16.17
Barium	8.0	9	10	12.	7.	7.5
Beryllium				11.8	5.76	6.23
Boron				6.41	7.5	6.31
Cadmium				13.9	28.	17.66
Chromium	5.94	11	10	3.73	3.	8.23
Cobalt	7.14	11	10			
Copper				5.65	5.09	2.1
Germanium					4.17	5.7
Hafnium	7.92	11	10			
Iron	7.3	11	10	6.98	0.43	1.45
Lanthanum	6.86	5	4			
Lead				7.11	12.14	6.28
Magnesium	7.47	4	5			
Manganese				9.81	4.	6.57
Mercury				0.9	0.68	
Molybdenum					4.92	15.12
Nickel	6.57	3	3	14.86	5.82	5.77
Protactinium	5.16	5	4			
Rubidium	5.39	11	10			
Scandium	6.79	11	10			
Selenium				0.4	1.45	4.66
Strontium	9.87	11	10			
Tantalum	7.5	11	10			
Thorium	7.87	11	10			
Titanium	6.65	4	4			
Ytterbium	5.65	5	5			
Zinc				2.3	1.48	12.5
Reference	59	59	59	60	60	60

*National Bureau of Standards

Table 42 summarizes the enrichment factors found in Tables 40 and 41. This table shows that fly ash will contain approximately 10 times the concentration of the trace elements (except for volatile trace elements; i.e., mercury, bromine, and chlorine) found in coal. This information can be used along with coal compositions found in Table 20 to predict the concentrations found in fly ash assuming that each individual element in each piece of coal in the United States is chemically and physically identical to that element in every other piece of coal in the United States. These values can be used with the data presented in Table 40 to estimate the elemental composition of fly ash. The amount of fly ash emitted by the boilers after treatment to acceptable standards is estimated to be 4.98×10^4 $\mu g/m^3$. These values can be used with the estimated fly ash elemental composition to estimate the air concentration of these elements due to the emitted fly ash. These calculations have been performed using the average enrichment factors and are shown in Table 43.

3.5.5.5 Oxygen Generation

The oxygen generator emits the following to the atmosphere (6):

Component	Mg/day	Concentration ($\mu g/m^3$)
Nitrogen	8711.	1.157×10^9
Argon	117.	1.55×10^7
Carbon dioxide	5.8	7.7×10^5
Hydrogen	1.2	$16. \times 10^5$
Neon, krypton, xenon	5.8	7.7×10^5
Water vapor	47.2	6.27×10^6
Oxygen	181.	2.40×10^7

TABLE 42. SUMMARY OF ENRICHMENT FACTORS (59,60)

Name	Number of Determinations	Arithmetic Mean	Geometric Mean	Standard Deviation	Range
Aluminum	1	5.9	5.9		
Antimony	5	7.	4.	10.	1.97-24.
Arsenic	6	11.	10.	3.	7.-16.17
Barium	6	10.	9.	4.	7.-16.
Beryllium	4	8.	8.	3.	5.76-11.8
Boron	4	7.	7.	1.	6.31-9.2
Bromine	1	<2.	<2.		
Cadmium	5	21.	20.	6.	13.9-28.
Calcium	1	4.2	4.2		
Cesium	1	12.	12.		
Chlorine	2	0.13	0.13	0.01	0.12-0.14
Chromium	7	9.	7.	8.	2.4-25.
Cobalt	3	10.	10.	3.	7.14-13.7
Copper	7	8.	6.	9	2.1-29.2
Europium	1	7.9	7.9		
Fluorine	1	ca.1.7	ca. 1.7		
Gallium	1	5.4	5.4		
Germanium	3	8.	7.	5.	4.17-14.
Hafnium	1	7.9	7.9		
Iron	5	5.	3.	3.	0.43-7.3
Lanthanum	2	6.5	6.5	0.5	6.2-6.86
Lead	5	10.	10.	4.	6.28-16.3
Lithium	1	8.6	8.6		
Magnesium	2	6.	6.	2.	5.3-7.47
Manganese	6	7.	6.	2.	4.-9.81
Mercury	5	0.5	0.4	0.3	0.1-0.9
Molybdenum	5	23.	16.	21.	4.92-54.5
Nickel	7	7.	6.	4.	3.3-14.86
Phosphorous	1	10.	10.		
Potassium	1	7.1	7.1		
Rubidium	2	8.	7.	3.	5.39-9.8
Scandium	1	6.8	6.8		
Selenium	4	16.	12.	15.	6.79-38.4
Silicon	1	6.	6.		
Sodium	1	9.2	9.2		
Strontium	2	6.	4.	6.	1.5-9.87
Tantalum	2	10.	9.	3.	7.5-12.
Tellurium	1	<10.	<10.		
Thallium	2	35.	32.	21.	20-50
Thorium	2	7.84	7.83	0.05	7.8-7.87
Tin	1	1.	1.		
Titanium	3	8.	8.	3.	5.6-11.9
Tungsten	1	5.	5.		
Uranium	1	7.2	7.2		
Vanadium	2	12.	12.	4.	9.1-15.4
Ytterbium	1	5.65	5.65		
Zinc	7	16.	9.	17.	1.48-49.3
Zirconium	1	2.5	2.5		
Using Arithmetic Means Above*	43	9.	8.	6.	1.-35.

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*Except for mercury, tellurium, bromine and chlorine.

TABLE 43. ESTIMATED ELEMENTAL COMPOSITION OF BOILER FLUE GAS DUE TO FLY ASH COMPONENT (59)

Name	Based on "Average U.S. Coal" Concentration ($\mu g/m^3$)	Based on "Maximum U.S. Coal" Concentration ($\mu g/m^3$)
Aluminum	4000.	5400
Antimony	0.76	3.2
Arsenic	6.0	19.
Barium	130	250.
Beryllium	0.55	1.2
Boron	19.	41.
Bromine	1.6	3.6
Cadmium	3.6	17.
Calcium	1600.	3600.
Cesium	0.72	1.2
Chromium	7.3	18.
Cobalt	5.1	12.
Copper	5.1	14.
Europium	0.13	0.53
Fluorine	ca. 8.6	ca.14.
Gallium	1.2	1.8
Germanium	2.5	5.5
Hafnium	0.32	0.47
Iron	3700	8200.
Lanthanum	3.1	4.9
Lead	6.5	32.
Lithium	15.	33.
Magnesium	330.	840.
Manganese	13.	48.
Mercury	0.0038	0.018
Molybdenum	5.9	14.
Nickel	6.6	42.
Phosphorous	52.	75
Potassium	810.	1800.
Rubidium	11.	40.
Scandium	0.18	1.0
Selenium	3.2	8.3
Silicon	6800.	8400.
Sodium	910.	4700.
Strontium	36.	77.
Tantalum	0.11	0.17
Tellurium	0.0013	0.0013
Thallium	1.1	1.1
Thorium	1.8	3.8
Tin	0.18	0.46
Titanium	210.	450.

(continued)

TABLE 43. (continued)

Name	Based on "Average U.S. Coal" Concentration ($\mu g/m^3$)	Based on "Maximum U.S. Coal" Concentration ($\mu g/m^3$)
Tungsten	0.18	0.20
Uranium	0.79	2.9
Vanadium	15.	30.
Ytterbium	0.18	0.23
Zinc	92.	1200.
Zirconium	7.1	9.2
Sulfur dioxide	6.4×10^5	
Nitrogen oxides	5.0×10^5	
Carbon monoxide	5.1×10^4	
Hydrocarbons	1.01×10^4	

The oxygen generator will also remove 2500 Mg oxygen per day from the atmosphere (6). The effect of removal should be minimal, however.

3.5.5.6 Other Sources of Hydrocarbon Emissions

Fugitive hydrocarbon emissions will be limited largely to leaks in pump seals, joints, flanges, compressors and from handling and venting operations. There are no estimates on the quantities of hydrocarbons lost in fugitive emissions, but the source is largely controllable through good maintenance practices. In many cases simply tightening pipe fittings and flanges will greatly reduce hydrocarbon emissions.

Possible sources of hydrocarbon emissions include:

- Coal pretreatment
- Liquefaction
- Separation
- Purification and upgrading
- Acid gas removal
- Hydrogen/hydrocarbon recovery
- Hydrogen generation

- Sulfur recovery
- Product and by-product storage
- Leaks from pipe systems and process vessel flanges and other fugitive emissions

All quantities of gas will continuously be disposed of in an elevated combustion flare system. While the flare loading cannot be estimated, a comparable size refinery flares about 13.6 Mg/day. Examination of combustion products from elevated flares shows the following relationship:

CO_2: hydrocarbons	2100:1
CO_2: CO	243:1

Other air contaminants depend upon the composition of the gas burned. Hydrogen sulfide will be emitted as sulfur dioxide. Nitrogen oxides will be emitted as a combustion contaminant.

The third area in which hydrocarbon emissions may be a problem is in product and by-product storage. In an environmental overview of a commercial SRC-II facility (61) product storage specifications have been made which should greatly reduce hydrocarbon emissions. The specifications for each fraction are given below.

LPG will be stored and shipped in heavy walled, pressurized tanks and consequently any hydrocarbon emissions would be fugitive losses from valves, fittings, and seals which must be regularly checked.

Naphtha should be stored in a floating roof storage tank. The floating roof will eliminate working losses which are the major source of hydrocarbon emissions. Floating roof standing storage emissions will vary depending upon tank design, age, and other factors. Based on a simplified estimation (62) we can expect between 5.44 g/day and 13.2 g/day for the 525 Mg/day of naphtha produced. We would expect 772 to 1907 g/day of hydrocarbon emissions from naphtha storage.

Fuel oil will be stored and shipped in atmospheric pressure tanks. Hydrocarbon emissions from fixed roof storage have been estimated at 4.56 g/m^3/day for breathing emissions and 120 g/m^3 for filling emissions. For fuel oil production rates of 2,615 Mg/day, hydrocarbon emissions will be approximately 0.32 Mg/day.

Product SRC-I is produced at a rate of 5,527 Mg/day and storage of this product will result in losses of roughly 0.66 Mg/day. Total hydrocarbon emissions are therefore a minimum of 0.98 Mg/day. The sum of the hydrocarbon emissions is about 1.3 Mg/day.

With these significant hydrocarbon emissions, the storage tank area would have a vapor recovery system to return vapors to the gas purification module. Loading faciltiies will also need a vapor recovery system to return vapor from the transport tanks to the storage tanks as the liquid is loaded.

3.5.5.7 Sulfur Recovery

Acid gas from the gas purification module (705 Mg/day) and gas from hydrogen production (5,912 Mg/day) are routed to the Stretford unit where H_2S is recovered as elemental sulfur. The process is greater than 99.5 percent efficient in sulfur recovery, yielding only 2.35 Mg/day of hydrogen sulfide.

Treatment of the tail gas may be by direct-flame incineration or by carbon absorption with incineration. The stream compositions after treatment are shown in Table 44.

TABLE 44. EMISSIONS AFTER TREATMENT OF STRETFORD TAIL GAS BY DIRECT FLAME INCINERATION (CONCENTRATION IN $\mu g/l$)

Component	
Hydrogen sulfide	$240\ \mu g/m^3$
Sulfur dioxide	4700
Hydrocarbons (as ethane)	9900
Nitrogen oxides (as NO)	$1.2x10^5$
Carbon monoxide	290
Carbon dioxide	$8.0x10^8$
Ammonia	1400

In either treatment method hydrogen sulfide emission standards for commercial gasifiers (state of New Mexico) are met. The New Mexico standard is 10 ppm (ca. 1400 $\mu g/m^3$). The sulfur emission standard for general operations is 0.014 kg/kcal (heat input of feed). At a coal heating value of $2.99x10^7$ joules/kg, the allowable sulfur discharge is 1.89 Mg/day. This standard could be met without tail gas treatment in this system. Industrial emission standards in Arizona require greater than 90 percent sulfur removal.

3.5.5.8 By-Product Storage

If Illinois No. 6 coal is utilized, as specified in the Standards of Practice Manual (6) then recovered sulfur can be estimated to be 444 Mg/day. The recovered sulfur is expected to have the composition given previously under products and emissions from sulfur storage and can be expected to have a similar distribution of trace elements.

Insofar as storage facilities have not been specified, it is not possible to estimate quantities of fugitive emissions from sulfur by-product storage. One possibility for preventing fugitive emissions would be to store by-product sulfur as a liquid. A more economic method would be to store sulfur in a lined pond with a water blanket.

3.6 Waste Streams to Water

Various studies on the pollution potential of coal conversion processes have cited effluent water quality as a particular area of concern since process waters contain cyanides, phenols, ammonia, sulfides, and dissolved solids. This would be of minimal concern in the commercial SRC facility if the water could be reused as has been suggested in the Standards of Practice Manual (6). Presently, the Fort Lewis, SRC pilot plant is demonstrating the applicability of various treatment systems to treat the wastewater for discharge. However, the wastewater is diluted with cooling water and therefore treatment results are not directly applicable to a commercial facility.

Organic pollutants generated in the proposed SRC plant will largely be formed within the process itself, with little contribution from hydrogen generation or other auxiliary facilities. The proposed Koppers-Totzek gasifier operates in the entrained flow mode and as such, the average bed temperatures are too high for phenols, tars and oil to be present in the discharged gas stream. Furthermore, ammonia and cyanides are formed in amounts well under one volume percent.

The data used to evaluate pollutant levels expected to be discharged from a once-through wastewater treatment system are based upon Fort Lewis pilot plant data (63-65), the AWARE report on the treatability of H-Coal wastewater (66), and analyses of Synthane gasifier process condensate (64). A comparison of the condensate from the two processes shows similarity in COD and phenol levels (64).

3.6.1 Coal Pretreatment

3.6.1.1 Coal Pile Runoff

Coal pile runoff results when moisture comes in contact with stockpile coal. The quantity and quality of coal pile runoff can be highly variable and this is reflected in the wide range of concentrations reported for several parameters monitored in coal pile runoff in Table 45.

The concentrations of dissolved and suspended solids from coal pile runoff will be highly variable. Table 45 shows a range of 247 to 44,050 mg/l for total dissolved solids and 22 to 3302 mg/l for suspended solids in coal due to runoff from several sources (67). The acidic nature of this runoff can cause the dissolution of inorganic salts which are present in the coal.

3.6.2 Coal Liquefaction

The aqueous effluent waste streams from the coal liquefaction module are collected and routed to the water treatment facility. Since the streams are combined, no estimates were practical on the uncombined streams. The quantity and composition of the effluent streams from the water treatment facility which will eventually interact with the environment are described under Section 3.6.5.

TABLE 45. CHEMICAL WASTES CHARACTERISTICS OF COAL PILE DRAINAGE (PPM)

Constituents	Number of Samples	Arithmetic Mean	Geometric Mean	Unbiased Standard Deviation	Range
Acidity (total), as $CaCO_3$	7	7400.	300.	12000.	8.68-27,810
Alkalinity	8	20.	0.0	28.	0.0-36.41
Biological Oxygen Demand	4	3.3	0.0	4.7	0.0-10.
Chemical Oxygen Demand	6	680	300	510.	9-1,099.
Conductance (μmhos/cm)	2	2250	2240	210	2,100-2,400
pH	13	4.2	3.8	2.0	2.8-7.8
Total dissolved solids	9	10,000	3200.	15,000	247-44,050
Total hardness (as $CaCO_3$)	6	800.	520.	660.	130-1850
Total solids	8	4200.	4400.	15000.	1330-45,000
Total suspended solids	9	800.	390.	990	22-3302
Turbidity, JTU	6	220	46.	240.	2.8-505
Aluminum	3	730	570.	500.	190-1200
Ammonia	5	0.69	0.00	0.82	0.00-1.77
Arsenic	2	0.01	0.01	0.00	0.009-0.001
Barium	1	0.1			
Beryllium	1	0.01			0.01-0.01
Cadmium	2	0.004	0.002	0.004	0.001-0.006
Calcium	2	300.	290.	80.	240-350
Chloride	5	100.	0	220	0-481
Chromium	8	2.	0.	6	0.0-15.7
Copper	6	1.5	1.1	1.1	0.18-3.4
Iron	11	9000	10.	28000	0.06-93,000
Lead	2	0.016	0.015	0.009	510-830
Magnesium	4	65	4.5	82.	0.023-174
Manganese	2	68.	54.	58	2.7-110.
Mercury	2	0.014	0.002	0.019	0.0002-0.027
Nickel	2	1.0	0.73	1.0	0.32-1.7
Nitrate	5	1.31	0.93	0.94	0.3-2.25
Phosphorus	2	0.72	0.53	0.69	0.23-1.2
Selenium	2	0.02	0.009	0.02	0.003-0.03
Silicon (dissolved)	1	91.			
Sodium	4	670.	180.	680.	4.1-1260.
Sulfate	1	2600.	2600.	-	2600-2600.
Titanium	1	1.	1.	-	1.-1.
Zinc	9	5.1	1.1	7.9	0.006-23

3.6.3 Separation

3.6.3.1 Gas Separation Process

The aqueous effluent waste streams from the gas separation module are collected and routed to the water treatment facility. Since the streams are combined, no estimates were practical on the uncombined streams. The quantity and composition of the effluent streams from the water treatment facility which will eventually interact with the environment are described under Section 3.6.5.

3.6.3.2 Solids/Liquids Separation Process

The aqueous effluent waste streams from the solids/ liquids separation module are collected and routed to the water treatment facility. Again, since the streams are combined, no estimates were practical on the uncombined streams. Characterization of the effluent streams from the water treatment facility which will eventually interact with the environment is described under Section 3.6.5.

3.6.4 Purification and Upgrading

3.6.4.1 Fractionation

The aqueous effluent waste streams from the fractionation module are gathered and sent to the water treatment facility. The streams are combined, so no estimates were made on the uncombined streams. The quantity and composition of the effluent streams from the water treatment facility which will eventually interact with the environment are described under Section 3.6.5.

3.6.4.2 Hydrotreating

The aqueous effluent waste streams from the hydrotreating module are collected and routed to the water treatment facility. Since the streams are combined, no estimates except those shown in Table 46 were practical on the uncombined streams. See Section 3.6.5 for a characterization of the effluent streams from the water treatment facility which will eventually interact with the environment.

TABLE 46. WASTEWATER COMPOSITION FROM HYDROTREATING MODULE (DECANTER WASTEWATER) (6)

Compound	Total Effluent Fraction of Input Coal	Total Effluent Mg/day	Concentration (μg/l)
Ammonia	3.486×10^{-4}	9.98	1.29×10^{7}
Hydrogen sulfide	3.169×10^{-4}	9.07	1.17×10^{7}

3.6.5 Auxiliary Facilities

3.6.5.1 Wastewater Treatment Facilities

Most wastewaters produced by SRC systems are combined for treatment as described in Section 4.0. The quantified sources and composition of wastewaters estimated by Rogoshewski and co-workers (6) are found in Table 47.

The process wastewater contributes almost all of the organic pollutants generated in the SRC facility. The foul water is the most polluted water in the overall process. The composition of this stream is estimated in Table 48.

TABLE 47. QUANTIFIED SOURCES AND COMPOSITION OF WASTEWATER

Module/Stream	Total Mg/day	Water Mg/day	Ammonia Mg/day	Hydrogen Sulfide Mg/day
Coal pile runoff	67	67		
Thickener underflow (35% solids)	3120	2020		
Water cooling	691			
Hydrogen generation	1535		452	
slag + water (60% slag) wastewaters	801			
Wastewater from acid gas removal[a]	554	2.9	1.4×10^{-4}	1.5
Hydrogen/hydrocarbon recovery[b]	33	32.	0.2	
Ammonia recovery	3825	3812	0.6	49.8
Phenol recovery (input from phase (gas)	3129	3000	54.2	40.7
separation) Output	3097	3000	40.7	40.7
Hydrotreating module (decanter wastewater)	793	774	10	9

[a] Also emitted from the acid gas removal module is 0.3 Mg carbon dioxide, 0.5 Mg, MEA, 0.003 Mg Polyrad 110a; 0.007 Mg oleyl alcohol and 0.3 Mg sodium hydroxide per day.

[b] Emitted from hydrogen/hydrocarbons recovery module also is 0.07 Mg hydrocarbons/day and 0.4 Mg phenols/day.

TABLE 48. CHARACTERIZATION OF FOUL PROCESS WATER

Component	Effluent Range (g/1)	Source of Data
Total organic carbon	6.6-7.3	Analysis of foul process condensate SRC; Kentucky - Bituminous Coal (68)
Total carbon	8.2-9.0	
BOD (5 days)	32.5	
COD	25.0-43.6	
Oil and grease	0.03-0.60	Foul process condensate H-Coal PDU (69)
Dissolved solids	2.7-5.3	
Suspended solids	0.002-0.020	

Foul water represents some 80 percent of process related wastewaters which consist of the following items (6):

- Foul process condensate-about 3130 m^3/day
- Decanter wastewater-hydrotreating - about 790 m^3/day
- Wastewater from gas purification - about 6 m^3/day
- Wastewater from cryogenic separation - about 33 m^3/day.

Nonprocess related water which will be treated in wastewater treatment units consists of:

Raw water	32,057 m^3/day
Cooling tower blowdown	693 m^3/day
Oily water runoff	Unquantified

3.6.5.2 Water Cooling Blowdown

The cooling tower blowdown can be expected to contain the same constituents that are present in the raw water. The concentration of trace elements in the blowdown depends upon the frequency of purge; and the chemicals used for corrosion inhibition and anti-fouling. It is not anticipated that dissolved solids from the cooling tower blowdown will present any problem, if the purge stream is treated in a side-stream ion-exchange or reverse osmosis process. The feasibility of these methods needs further investigation.

Nonoxidizing biocides used to control growth of slime, algae and fungi are obviously toxic and cannot be discharged directly. Since ion exchange or reverse osmosis are the treatment methods recommended, it is best to choose a biocide which can be neutralized chemically.

3.6.5.3 Other Potential Water Effluents

3.6.5.3.1 Tailings Pond

Coal pile runoff and thickener underflow are proposed to be routed to a tailings pond as discussed in Section 4.0. Except in instances of severe precipitation (e.g., flooding) no aqueous discharge from the tailings pond is anticipated.

3.6.5.3.2 Ash Ponds

Coal utilized in the steam generation module is anticipated to generate roughly 66 Mg/day of bottom ash and 36.6 Mg/day of particulates in the stack gas. The fly ash will be collected in hoppers below the mechanical collectors or electrostatic precipitators. It is possible that the ash will be mixed with a high velocity water jet, and then sluiced through cast iron alloy pipes to a settling pond. Bottom ash is removed from the bottom of the boiler using a high pressure spray system. This ash-water mixture will also be pumped to the settling pond. Alternatively, the ashes could be hauled off-site, which would eliminate any pollution potential from the ash ponds.

The characteristics of the ash pond are not only affected by the coal type but also by the quality and quantity of water used for sluicing.

The characteristics of ash pond effluent for coal-fired power plants which use Illinois or western Kentucky coals are shown in Table 49 (67). Since the volume of the effluent is quite site specific no SAM/IA analysis was performed other than calculation of the potential degree of hazard. In both plants suspended solids concentrations are much lower than concentrations of dissolved solids. Nevertheless, suspended solids levels are too high to meet BPCTCA or BATEA levels of 30 mg/l for bottom ash or fly ash transport water. The high concentrations of suspended solids in some ash ponds are probably caused by low density, hollow sphere ashes (cenospheres) which cannot be removed in the pond by natural settling. Some means of removing the cenospheres would be required to meet effluent guidelines for suspended solids if the water was discharged. It is more likely that the water will be reused in the process, although its use is restricted by high levels of dissolved solids. Complete reuse would require dissolved solids removal by reverse osmosis, electrodialysis or ion exchange.

3.6.5.3.3 Refuse Pile Runoff

Many of the same variables influencing the quality of coal pile runoff also affect the quality of refuse pile runoff. In the case of the refuse pile, however, sealing techniques may be used to reduce the amount of moisture infiltration and subsequent leaching of coal refuse material.

Data in Table 50 show refuse pile runoff from a bituminous coal refuse pile covered with clay and grass and, for comparison, a refuse effluent from a pile which was not covered (71).

TABLE 49. CHARACTERISTICS OF ASH POND EFFLUENT FROM COAL-FIRED POWER PLANTS RUN ON KENTUCKY BITUMINOUS OR ILLINOIS COAL (70)

Parameter	Plant 1[a]			Plant 2[b]		
	Min (mg/l)	Ave (mg/l)	Max (mg/l)	Min (mg/l)	Ave (mg/l)	Max (mg/l)
Total alk. ($CaCO_3$)	33	113	173	58	96	187
pH	10.5	11.2	11.4	9.4	10.8	11.4
Dissolved solids	12	452	1410	23	232	416
Suspended solids	1	39	182	2	14	59
Aluminum	0.8	2.0	3.1	0.5	1.7	2.4
Ammonia	0.03	0.15	0.38	0.02	0.06	0.16
Arsenic	<0.005	<0.005	0.005	<0.005	0.012	0.025
Barium	<0.1	0.2	0.5	<0.1	0.2	0.3
Beryllium	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Cadmium	0.001	0.001	0.002	0.001	0.001	0.001
Calcium	74	115	160	52	87	130
Chloride	4	5	6	7	12	19
Chromium	0.012	0.043	0.072	0.014	0.021	0.026
Copper	0.01	0.02	0.04	<0.01	0.05	0.10
Cyanide	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Iron	0.05	0.23	1.10	0.11	0.24	0.34
Lead	<0.01	0.01	0.04	<0.01	0.025	0.04
Magnesium	0.2	2.0	7.2	0.4	1.0	3.0
Manganese	<0.01	0.01	0.04	<0.001	0.001	0.02
Mercury	≤0.0002	0.038	0.300	<0.0002	0.0004	0.0008
Nickel	<0.05	<0.05	<0.05	0.05	0.07	0.22
Selenium	0.009	0.016	0.028	<0.002	0.011	0.016
Silver	<0.001	<0.01	<0.01	<0.01	<0.01	<0.01
Sulfate	14	156	240	55	87	110
Zinc	<0.01	0.04	0.06	<0.01	0.05	0.11

[a] Plant 1 - utilized W. Kentucky and/or S.
Illinois coal method of firing - opposed
Ash content of coal - 16.3%
% fly ash of total ash - 80%

[b] Plant 2 - utilized W. Kentucky and/or S. Illinois coal
method of firing - circular
ash content of coal - 15.6%
% fly ash of total ash - 75%

TABLE 50. EFFECTS OF REFUSE PILE RUNOFF ON STREAM COMPOSITION (71)

Stream Component	Pile Covered With Clay and Grass: Above Pile (mg/l)	Pile Covered With Clay and Grass: Below Pile (mg/l)	Pile With No Cover: Above Pile (mg/l)	Pile With No Cover: Below Pile (mg/l)
Total acidity	0	0	-	5,660
pH	7.5	7.5	7.9	2.9
SO_4	106	106	564	10,544
Na	16	16	20	256
Mg	35	35	No Data	No Data
Al	1.0	1.0	No Data	No Data
K	2.2	2.5	No Data	No Data
Ca	70	70	No Data	No Data
Mn	0.01	0.01	0.03	10
Fe	0.1	0.1	0.5	2,233

It is quite evident from the data that runoff from an uncovered refuse pile would pose serious threats; the data showed that the concentration of iron and SO_4 increases 4,466 and 18.7 times, respectively, and that the stream adjacent to the refuse pile was extremely acidic.

3.6.5.3.4 Leachate from Slag

The leachability of slag generated by Koppers-Totzek needs to be investigated. It is anticipated that the slag will behave as bottom ash, and as such, will not leach readily.

Slag could ultimately be disposed in the strip mine, and bottoms from the ash pond are likely to be disposed with the slag.

3.6.5.4 Other Characteristics of SRC Wastewater

3.6.5.4.1 COD, BOD and TOC

The treatability and final effluent levels for non-chemical water parameters can only be accurately evaluated by actual plant data. Residual concentrations can only be roughly estimated.

Phenol concentrations in the foul water process condensate range from 5,000 to 12,000 mg/l which represents between 47 to 64 percent of the total COD (72). Phenol recovery should reduce the COD concentrations to 13,490 to 23,500 mg/l. The ability of activated sludge to reduce COD in the foul process condensate was investigated by AWARE Associates for the H-Coal process (66). As expected, removal efficiency is dependent upon loading rates to the activated sludge units. Operational data indicate that a removal rate of 0.22 g BOD/g MLVSS-day be used for design. Under the optimum conditions of this investigation, 99 and 93 percent of the influent BOD and COD, respectively, could be removed. Influent COD ranged from 2700 to 4200 mg/l and influent BOD ranged from 1700 to 2700 mg/l. The refractory BOD and COD were 5 mg/l and 150 mg/l respectively. Foul process condensate would have to be diluted significantly to obtain these desired organic loading rates. An alternative would be to use high purity oxygen activated sludge (HPOAS). Experience with HPOAS systems in the coking industries suggests that this may be an effective treatment method. Effluent soluble BOD_5 of 45 mg/l can be successfully achieved for the following loading conditions (69):

- BOD_5 - 18,000 mg/l
- COD - 28,000 mg/l
- COD/BOD_5 - 1.56

The effectiveness of the method for treatment of liquefaction wastewaters, in which readily degraded phenols make up less of the total COD, needs to be tested. Phenols have been estimated to make up 68 percent of the COD of coking effluents.

The use of activated carbon for tertiary treatment has been shown to effectively reduce COD in treatment of the pilot plant wastewater (66); however, activated carbon absorption of industrial wastes must be carefully evaluated. Breakthrough geometry and adsorption kinetics of multicomponent wastewaters are difficult to define. Certain organics which would be encountered are not amenable to activated carbon treatment. A third problem area with activated carbon is that regeneration on carbon capacities are variable and unpredictable. Carbon adsorption pilot plant results from petrochemical and refinery wastewaters show that for a COD of 100 to 150 mg/l, the percent removal ranges from 59 to 67 percent (69). Assuming that 150 mg/l COD is the refractory COD from biological treatment, as observed for the H-Coal foul process condensates, effluent COD's may be as low as 49.5 to 61.5 ppm.

If the refractory BOD is closer to 45 ppm, we may expect a COD of approximately 340 mg/l from biological treatment. This treatment assumes that the relationship:

$$BOD_T = 0.66\ COD_T - 180$$

determined for the H-Coal sour water (66) holds true for SRC sour water as well.

3.6.5.4.2 Oil and Grease

Oil and grease will be removed in wastewater treatment largely by dissolved air flotation, possibly accompanied by an API separator. The main source of oil and grease is the foul process condensate and oily water runoff. The contribution by the latter is unknown and variable.

Bench scale application of dissolved air flotation to the H-Coal foul process condensate showed oil and grease removal efficiency of 70 percent without emission breaking chemicals. The following ranges of oil removal efficiencies have been reported for dissolved air flotation (DAF) (73);

	Oil Removed - Free Oil	Oil Emulsions
Air flotation (no chemical)	70-95%	10-40%
Air flotation and emulsion breaking chemicals	75-95%	50-90%

There are few states with discharge criteria for oil and grease. Colorado has an effluent discharge standard of 10 mg/l. Use of DAF alone would probably be insufficient to meet these standards. Addition of emulsion breaking chemicals may increase efficiency up to 90 percent. During stable operations of activated sludge units treating H-Coal sour water, oil and grease concentrations were reduced by 75 to 90 percent for influent concentrations ranging from 20 to 75 mg/l (69). Therefore, use of activated sludge and DAF with emulsion breaking chemicals should reduce oil and grease to acceptable levels.

3.6.5.4.3 Dissolved and Suspended Solids

There are several waste streams which require treatment for dissolved and suspended solids, the degree of treatment depending largely upon the end use of the water.

3.6.5.4.4 Dissolved and Suspended Solids in Foul Process Water

As was mentioned earlier, dissolved and suspended solid levels in the foul process condensate are 2690 to 5390 mg/l and 2 to 20 mg/l, respectively.

The very low level of suspended solids (2 to 20 ppm) from the process water do not warrant treatment. Dissolved solids, on the other hand, are very high (2690 to 5300 ppm) and removal efficiencies in wastewater treatment depend upon the particular dissolved species. Dissolved solids, as such, are not particularly harmful assuming that the individual pollutants are not toxic.

3.6.5.4.5 Solids in Cooling Tower Blowdown

The blowdown from the recirculating cooling system has the same chemical composition as does the recirculating cooling water. Soluble constituents in makeup water, however, are concentrated as high as 1500 mg/l to 10,000 mg/l before being removed in the blowdown stream. A sidestream filter should remove most suspended solids generated in the cooling system. It has been conceptualized that the blowdown be treated separately, using reverse osmosis or ion exchange to remove dissolved solids to acceptable levels; these processes are highly effective in removing suspended solids. Thus, it may be necessary to only treat a portion of the stream and to recombine the treated and untreated streams before discharge. The feasibility and cost effectiveness of these treatment methods remain to be demonstrated.

3.6.5.4.6 Straight Chain Hydrocarbons

Long chain alkanes and fatty acids have been detected in process wastewater from several coal conversion processes. MEGs have not been assigned to long chain fatty acids or to long chain alkanes to date. Long chain alkanes detected in the SRC foul water are given in reference 47. Straight chain alkanes from crude oil have been found to be degraded about 96.4 percent by microorganisms isolated from the Chesapeake Bay (73).

Very low concentrations of long chain alkanes can be expected in the bio-effluent. Fatty acids have been observed in process condensate from Synthane, COED (73) and EDS processes (70). Fatty acids have not been reported in SRC foul water to date

3.6.5.4.7 Heterocyclic N-Aromatics

Polycyclic N-aromatics have been observed in the process wastewater from the Synthane gasification process.

3.6.5.4.8 Organic Constituents of Bio-Unit Effluent

The organic constituents of the bio-unit effluent are estimated in Table 51. For the purposes of this report, these concentrations will be taken as the final concentrations in the wastewater effluent from the facility to the environment.

TABLE 51. ORGANIC CONSTITUENTS OF BIO-UNIT EFFLUENT

Component	Bio-Unit Effluent µg/l
Phenol	390
Cresols	940
Xylenol	380
C_3-phenols	90
Methyllindane	2400-8400
Tetralin	50
Dimethyltetralin	80-400
Naphthalene	810
Dimethylnaphthalene	50-1120
2-Isopropylnaphthalene	110.-390.
1-Isopropylnaphthalene	320-1120.
Biphenyl	30-110
Acenaphthalene	10-60
Dimethylbiphenyl	790-1100.
Dibenzofuran	90-320
Xanthene	10-60
Dibenzothiophene	240.
Methyldibenzothiophene	10-60
Thioxanthene	10-60.
Fluorene	80.
9-Methylfluorene	50-170
1-Methylfluorene	40.
Antracene/Phenanthrene	260.
Methylphenanthrene	50-110.
C_2-Anthracene	10
Fluoranthene	60-630
Dihydropyrene	7-30
Pyrene	240
Dimethyldibenzothiophene	7-30.
Dimethylquinoline	$0-1.0 \times 10^5$
Dimethylindole	$0-1.1 \times 10^5$
α- naphthol	
β- naphthol	300-2900
methylnaphthol	
indenol	200-1100
C_1-indenol	400-1500
4-indenol	

3.6.5.4.9 Trace Elements

Trace element concentrations have been estimated using the partitioning factors described previously as well as using the values found in the Standards of Practice Manual (6). These data are found in Table 52.

3.6.5.4.10 Final Wastewater Effluent

The organic component of the final wastewater was assumed to be that composition emanating from the bio-unit (Table 51). The final inorganic component was assumed to be the trace element composition given in Table 52.

Most trace elements in this stream are present in the dissolved state. How they behave in wastewater treatment is not well known. The treatability of these trace elements and organic compounds needs to be further investigated. Often concentrations of these materials remaining in effluents are higher than is predicted by the solubility product alone, due either to incomplete precipitation or to the presence of finely divided colloidal particles. Table 53 shows estimates of the removal efficiency for several trace elements by precipitation and carbon absorption.

TABLE 53. SUMMARY OF REMOVAL OF METALS BY CHEMICAL CLARIFICATION AND CARBON ADSORPTION (74)

Percent Removal	Lime System	Ferric Chloride System	Alum System
50	Mo	Co, Tl	Mo,Tl,Zn,Mn,Ni
50-90	Sb,Se*	Mo,Sb,Se	Co,Cd,Sb,Se
90-95	Hg,Sn,Tl,V	Ti	Sn,Ba
95-100	Ag,Be,Bi,Co,Se,** Ti	Ag,Be,Bi,Hg,Sn, V	Ag,Be,Bi,Hg,Ti, V,Cr,Cu,Pb

* Initial concentration - 0.06 mg/l.
**Initial concentration - 0.5 mg/l.

TABLE 52. PARTITIONING FACTORS AND ESTIMATED CONCENTRATION OF INORGANICS IN SRC WASTEWATER

Name	Partitioning Factors: Number of Determinations	Partitioning Factors: Arithmetic Mean	Partitioning Factors: Geometric Mean	Partitioning Factors: Unbiased Standard Deviation	Partitioning Factors: Range	Estimated Wastewaters Composition (μg/1): Avg.	Estimated Wastewaters Composition (μg/1): Max.	Estimated Wastewaters Composition (μg/1)
Aluminum	2	$1.85x10^{-5}$	$1.83x10^{-5}$	$0.35x10^{-5}$	$1.6-2.1x10^{-5}$	250.	340.	
Antimony	2	$1.5x10^{-6}$	$1.1x10^{-6}$	$1.5x10^{-6}$	$0.45-2.6x10^{-6}$	0.0033	0.0075	2^b
Arsenic	2	$<3x10^{-5}$	$<10^{-6}$	$>4.6x10^{-5}$	$<0.008-8x10^{-5}$	0.33	1.1	< 1
Barium	2	$<5x10^{-4}$	$<4x10^{-4}$	$>4x10^{-4}$	$<2-<9x10^{-4}$	125.	250	<40
Bismuth								32000
Bromine	2	$4.8x10^{-6}$	$4.3x10^{-6}$	$3.1x10^{-6}$	$2.7-7.0x10^{-6}$	0.077	0.17	
Calcium	3	0.011	0.011	0.004	0.0069-0.015	85,000	190,000	
Cerium	2	$1.6x10^{-7}$	$0.6x10^{-7}$	$2.1x10^{-7}$	$<0.1-3.1x10^{-7}$	0.0029	0.0040	
Cesium	3	0.0043	$2.8x10^{-6}$	0.0074	$2.7x10^{-8}-0.0128$	5.2	8.6	<0.02
Chlorine	1	0.0065	0.0065	-	0.0065-0.0065	6500.	11000.	0.02
Chromium	2	0.0055	$8.7x10^{-5}$	0.0078	$6.8x10^{-7}-0.011$	90.	220.	150
Cobalt	2	$6.95x10^{-8}$	$6.95x10^{-8}$	$0.07x10^{-8}$	$6.9-7.0x10^{-8}$	$7.1x10^{-4}$	0.0017	0.41
Copper	2	0.0009	$2.9x10^{-5}$	0.0012	$<5.0x10^{-7}-0.0017$	11.	30.	< 10.
Europium	2	$5.8x10^{-8}$	$5.5x10^{-8}$	$2.5x10^{-8}$	$4.0-7.8x10^{-8}$	$1.9x10^{-5}$	$3.0x10^{-5}$	0.01
Gallium	2	$6.0x10^{-4}$	$3.5x10^{-5}$	$8.5x10^{-4}$	$1-1200.x10^{-6}$	2.6	4.2	< 0.04
Hafnium	2	$2.7x10^{-8}$	$2.6x10^{-8}$	$1.0x10^{-8}$	$2.0-3.4x10^{-8}$	$2.2x10^{-5}$	$3.2x10^{-5}$	< 0.01
Iron	2	$3.8x10^{-5}$	$3.2x10^{-5}$	$3.0x10^{-5}$	$1.7-5.9x10^{-5}$	560.	1250.	1250.
Lanthanum	1	$7x10^{-8}$	$7x10^{-8}$		$7-7x10^{-8}$	$6.7x10^{-4}$	0.0010	< 0.5
Magnesium	3	0.0016	0.0016	0.0001	0.0016->0.0017	1800.	4500.	3200.
Manganese	2	$5.6x10^{-4}$	$4.9x10^{-4}$	$3.9x10^{-4}$	$2.9-8.4x10^{-4}$	20.	77.	
Mercury	3	0.026	0.011	0.24	0.00087-0.048	3.9	19.	
Nickel	1	$8.1x10^{-7}$	$8.1x10^{-7}$		$8.1-8.1x10^{-7}$	0.015	0.098	$13.^b$
Potassium	2	$6.5x10^{-4}$	$6.3x10^{-4}$	$2.3x10^{-4}$	$<4.9-8.1x10^{-4}$	1500.	3250.	1260.
Rubidium	3	$8.8x10^{-8}$	$8.2x10^{-8}$	$3.5x10^{-8}$	$0.48-1.15x10^{-7}$	0.0025	0.0088	
Samarium	2	$4.6x10^{-8}$	$4.3x10^{-8}$	$2.2x10^{-8}$	$3.0-6.1x10^{-8}$	$7.1x10^{-5}$	$1.2x10^{-4}$	$< 0.06^b$
Scandium	3	$3.8x10^{-8}$	$2.3x10^{-8}$	$3.0x10^{-8}$	$0.39-6.1x10^{-8}$	$1.3x10^{-4}$	$2.2x10^{-4}$	0.01^b
Selenium	3	$2.0x10^{-4}$	$0.035x10^{-4}$	$3.5x10^{-4}$	$0.0012-6.0x10^{-4}$	0.80	2.1	1.2
Sodium	2	0.059	0.059	0.002	0.058-0.061	$1.2x10^5$	$6.1x10^5$	8300
Strontium	2	$2.8x10^{-4}$	$1.8x10^{-4}$	$3.1x10^{-4}$	$0.63-5.0x10^{-4}$	34.	73.	< 40.
Tantalum	2	$0.9x10^{-6}$	$0.3x10^{-6}$	$1.1x10^{-6}$	$0.07-1.7x10^{-6}$	$2.2x10^{-4}$	$3.0x10^{-4}$	< 0.01
Terbium	2	$2.85x10^{-8}$	$2.84x10^{-8}$	$0.35x10^{-8}$	$2.6-3.1x10^{-8}$	$5.7x10^{-6}$	$9.7x10^{-6}$	0.01
Thorium	2	$2.6x10^{-8}$	$1.5x10^{-8}$	$3.0x10^{-8}$	$0.5-4.7x10^{-8}$	$1.2x10^{-4}$	$2.5x10^{-4}$	< 0.01
Titanium	4	$<2.35x10^{-4}$	$2.25x10^{-4}$	$0.77x10^{-4}$	$<1.5-<3.0x10^{-4}$	120.	270.	
Vanadium	2	$4.8x10^{-5}$	$4.4x10^{-5}$	$2.5x10^{-5}$	$3-6.6x10^{-5}$	1.2	2.4	
Zinc								< 0.04
Zirconium	2	$4.4x10^{-4}$	$4.0x10^{-4}$	$2.8x10^{-4}$	$2.5-3.2x10^{-4}$	25.	48.	
All Arithmetic means above	34	0.003	0.001	0.011	$2.6x10^{-8}-0.059$			
All maximum above	34	0.005	0.001	0.013	$3.1x10^{-8}-0.061$			

3.7 Solid Wastes to Final Disposal

As air and water pollution regulations are implemented, sludges and slurries which are toxic and/or hazardous are generated at increasingly large quantities. It is assumed for this discussion that most of the solid wastes generated will be disposed of by landfilling; this means of disposal is advocated in two other reports dealing with the SRC process (6) and (61).

3.7.1 Coal Pretreatment

3.7.1.1 Coal Pile Refuse

Refuse generated in coal pretreatment consists of refuse from reclaiming and crushing which consists of tramp iron, slate, and coal. The total waste generated amounts to some 7,713 Mg/day with a moisture content of 24 percent. Refuse generated consists of materials ranging from colloidal size to 30 cm long (75).

It is not possible to develop a characterization profile for refuse dumps. The chief concern is actually pollutant discharge in the form of fugitive emissions and runoff or of leachate as previously discussed.

Ultimate disposal of coal refuse will probably consist of disposal in the strip mines with the slag and fly ash from gasification.

3.7.2 Coal Liquefaction, Gas Separation and Hydrotreating

Coal liquefaction and gas separation discharge no solids to the environment. Periodically, spent catalyst is removed from hydrotreating, however no characterization data are available.

3.7.3 Fractionation

In the hypothetical SRC-II facility, it has been estimated that 4075 Mg/day of residue will not be used in hydrogen production, due to operational problems resulting from the high ash content of the residue (64 percent) (6). However, the high carbon content of the residue (27 to 28 percent) (75,76), indicates that this solid should be further utilized to recover useful energy.

Since it is unlikely that the residue will be disposed of, as such, our solid waste problem is a temporary one. In an effort to determine the leachability of the residue (68), efforts were made to dissolve the solid in dilute acid. Efforts failed to produce any leachate over the test period. It is not anticipated that temporary storage would cause any significant leaching problems.

3.7.4 Solids/Liquids Separation Process

Table 54 shows the organics quantified in the SRC-I filter cake. This analysis was performed on a residue derived from Kentucky bituminous coal during operation of SRC-I process. Differences in the organic content of the residue under the operating conditions for SRC-II are expected. Table 55 shows the inorganic constituents of the filter cake as estimated using partitioning factors as described previously.

TABLE 54. ORGANICS QUANTIFIED IN SRC-I FILTER CAKE RESIDUE FROM KENTUCKY BITUMINOUS COAL

Compound	Concentration (μg/g)	Compound	Concentration (μg/g)
PAH Fraction		Neutral Fraction	
Indane	85	n-undecane	90
Methylindane	40	n-dodecane	550
Dimethylindane	25	n-tridecane	9,100
Tetralin	110	n-tetradecane	210
Dimethyltetralin	35	n-pentadecane	80
6-Methyltetralin	50	n-hexandecane	50
Naphthalene	1,500	n-heptadecane	20
2-Methylnaphthalene	740	n-octadecane	10
1-Methylnaphthalene	180	n-nonadecane	14
Dimethylnaphthalene	870	n-eicosane	14
2-Isopropylnaphthalene	470	n-heneicosane	16
1-Isopropylnaphthalene	2	n-docosane	14
C_4-Naphthalene	15	n-tricosane	14
Cyclohexylbenzene	1	n-tetracosane	10
Biphenyl	5	others	26
Acenaphthylene	270		
Dimethylbiphenyl	61		
Dibenzofuran	60		
Xanthene	20		
Dibenzothiophene	70		
Methyldibenzothiophene	8		
Dimethyldibenzothiophene	20		
Thioxanthene	5		
Fluorene	80		
9-Methylfluorene	40		
1-Methylfluorene	50		
Anthracene/phenanthrene	500		
Methylphenanthrene	100		
1-methylphenanthrene	50		
C_2-Anthracene	10		
Fluoranthene	200		
Dihydropyrene	10		
Pyrene	200		

TABLE 55. PARTITIONING FACTORS AND ESTIMATES OF INORGANIC CONSTITUENTS IN SRC-II MINERAL RESIDUE FILTER CAKE

		Partitioning Factors				Estimated Mineral Residue Composition		Actual
Name	Number of of Determination	Arithmetic Mean	Geometric Mean	Unbiased Standard Deviation	Range	Avg.	Max.	Estimated Composition (μg/g)
Aluminum	2	4.4	3.9	2.8	2.8-6.30	58,760	81,400	
Antimony	3	5.7	5.6	1.8	4.3-7.7	13.	28.	5.2
Arsenic	4	5.1	4.9	1.8	4.0-7.8	56.	180.	25.
Barium	3	4.94	4.94	0.26	4.71-5.22	1235.	2470.	580
Beryllium	3	5.	4.	54.	2.0-10.0	7.	15.	
Boron	3	4.6	4.1	2.2	2.0-6.0	250.	550.	
Bromine	4	1.37	1.36	0.09	1.24-1.44	22.	49.	19.
Cadmium	3	1.81	1.69	0.76	1.60-2.50	6.2	29.	
Calcium	3	13.6	13.8	5.0	7.7-16.7	105,000	230,000	33,323
Cerium	2	5.6	5.5	1.6	4.5-6.7	100.	140.	71.
Cesium	2	5.6	5.6	1.3	4.7-6.7	6.7	11.	7.3
Chlorine	3	3.62	3.62	0.23	3.37-3.80	3600.	6200.	
Chromium	7	7.3	5.8	4.1	1.0-13.3	120	290	178.
Cobalt	6	4.3	3.3	2.2	0.5-6.6	44.	110.	4.1
Copper	6	6.5	5.5	3.8	2.1-12.6	83.	220.	8.0
Europium	2	4.6	4.5	1.2	3.8-5.4	1.5	2.4	1.2
Gallium	2	4.6	4.5	0.6	4.1-5.0	20.	32.	
Hafnium	3	4.94	4.92	0.60	4.25-5.35	4.1	5.9	2.7
	4	6.2	6.1	1.2	4.6-7.3			
	4	6.2	6.1	1.2	4.6-7.3	92000	$2.0x10^5$	$1.2x10^5$
	3	5.91	5.86	0.90	5.26-6.93	57	80	
Lead	1	5.2						
Magnesium	1	4.5						
Manganese	5	6.7	4.6	7.5	2.1-20.0	240.	920.	
Mercury	3	5.1	1.2	5.2	0.031-10.3	0.76	3.7	
Molybdenum	2	4.2	4.1	1.2	3.3-5.0	22.	50.	
Nickel	7	5.0	3.8	2.8	0.4-9.5	95.	600.	126.

(continued)

TABLE 55. (continued)

Name	Number of of Determination	Partitioning Factors Arithmetic Mean	Partitioning Factors Geometric Mean	Unbiased Standard Deviation	Range	Estimated Mineral Residue Composition Avg.	Estimated Mineral Residue Composition Max.	Actual Estimated Composition ($\mu g/g$)
Potassium	3	7.9	7.5	3.3	5.5-11.6	18000.	40000	
Rubidium	4	8.6	7.9	4.6	6.3-15.5	240.	860.	
Samarium	2	4.84	4.84	0.23	4.68-5.00	7.4	12.6	
Scandium	2	4.6	4.5	1.3	3.6-5.5	16.	27.	15.
Selenium	3	4.9	4.6	2.2	3.6-7.4	20.	51.	12.
Sodium	6	9.4	4.9	7.4	0.2-17.5	19000.	97000.	1200.
Strontium	4	4.7	3.9	3.3	2.0-9.1	560.	1200.	
Tantalum	2	4.3	4.2	1.1	3.5-5.1	1.0	1.4	0.71
Terbium	2	3.4	2.1	3.9	0.7-6.2	0.68	1.1	0.69
Thorium	3	5.06	5.02	0.75	4.52-5.91	23.	49.	
Titanium	6	2.9	2.4	1.5	0.5-4.9	1500.	3300.	
Uranium	1	6.6	6.6		6.6-6.6	15.	53.	11.
Vanadium	6	5.9	5.1	3.0	2.1-10.0	150.	300.	
Ytterbium								2.6
Zinc	2	3.3	3.0	1.8	2.0-4.6	400.	4800.	1940
Zirconium	2	5.6	5.4	2.0	4.2-7.0	320.	620.	
All Arithmetic means above	41	5.3	5.0	2.0	1.4-13.6			
All maximums means above	41	7.8	6.9	4.1	1.4-20.0			

3.7.5 Auxiliary Processes

3.7.5.1 Sulfur Recovery

There is a continuous purge stream from the Stretford unit. It is recommended that this purge stream be decomposed by high temperature hydrolysis (6). This will recover vanadium in solid form along with some sodium carbonate, sodium sulfide and sodium sulfate.

Hydrogen cyanide is converted to CO_2, H_2O and N_2, and sodium thiosulfate is converted to H_2S, and H_2O. This purge stream has the following composition (Table 56):

TABLE 56. ABSORBENT PURGE FROM THE STRETFORD UNIT (6)

Compound	g/Mg of Coal	Conc. (μg/l)
$Na_2S_2O_3$	68.1	1.1×10^5
NaCNS	28.0	4.4×10^4
$NaVO_3$	4.13	6800
ADA*	7.02	1.1×10^4
Na_2CO_3, $NaHCO_3$	19.0	3.0×10^4
H_2O	503.9	8.0×10^5

*Sodium anthraquinone disulfonate.

Stream flow rate: 164 g/sec.
Mates not available.

3.7.6 Process Sludges

The sludges generated in the SRC facility are generally hazardous wastes and must be disposed accordingly. This discussion will consider the following sludges:

- Surge tank bottoms
- Froth skimmed from air-flotation unit
- Biounit sludge
- Chromate reduction unit sludge
- Raw water treatment sludge (lime sludge)
- Desulfurization sludge

Landfilling is presently the most attractive for the large quantities of sludge generated. A high pressure sludge dewatering system will be needed to convert the sludges into a filter cake suitable for disposal.

3.7.6.1 Surge Tank Bottoms

Residence time in the surge tank must be sufficient to allow for settling of heavy sediment. In the case of the surge tank utilized at the SRC pilot plant, much of the heavy oil which accumulated on the bottom can be recovered. However, an unquantified amount which must be disposed forms a stable emulsion with oil (77).

3.7.6.2 Air Flotation Skimmings

In the air flotation unit remaining suspended solids and entrained oils from the process wastewater are removed. The concentration of air flotation skimmings is approximately 0.25 percent solids (by wt.) (78). It is unlikely that this sludge will be disposed as such. Rather, the skimmings will be sent through a series of hot and cold settling in which most of the oil and water are recovered. There will be a small but unquantified amount of resolved emulsions after treating.

3.7.6.3 Biounit Sludge

An estimation of sludge production is based upon design data which make the following assumptions:

- 0.48 g of volatile suspended solids (VSS)/g BOD removal (79)
- Removal of 200 ppm (wt.)
- Volatile solids concentration of waste sludge equals 70 percent.

For a wastewater treatment system receiving 1.0-1.2 x 10^3 m^3/day, one can expect roughly 0.54-0.65 Mg/day of sludge.

3.7.6.4 Sludge from Water Cooling

Corrosion inhibitors used in the cooling tower will be assumed to be hexavalent chromium, zinc, and phosphonate. A chromate reduction unit will be required to remove the chromium from the cooling tower blowdown. The discharge from this unit contains zinc sulfide and trivalent chromic/ferric hydroxide complex which has precipitated out. These compounds are difficult to settle and will require use of a coagulant aid. The concentration of chromate required for corrosion inhibitor can be reduced by adding zinc and phosphonate (80). The following additives are assumed:

Chromate	20 to 25 ppm
Zinc	2 to 5 ppm
Phosphonate	(Dosage sufficient to act as a metal passivator and scale inhibitor (20 to 50 ppm)) (80)

The wastewater treatment sludges may be combined and chemically conditioned to improve specific resistance to filtration. The final filter cake will most likely be landfilled.

3.7.6.5 Raw Water Treatment Sludge

Raw water requirements for the commercial SRC facility amount to 31,711 m^3/day for a facility in which the process water is recirculated, and roughly 36,280 m^3/day for a once-through system. The major waste stream discharged from the raw water treatment facility is sludge removed from the clarifiers. The raw water is treated with lime and sodium carbonate and the resultant sludge is characterized as follows below. It is recommended that the lime be recovered from this sludge. Not only are valuable chemicals recovered but the moisture content is reduced nearly 10 fold. The sludge remaining to be landfilled amounts to 48.5 Mg/day.

Component	Recirculated Process Water (Mg/day)	Once-Through System (Mg/day)
Water	351.6	402.2
$CaCO_3$	16.0	18.3
$Mg(OH)_2$	0.9	1.0
$Ca_5(OH)(CO_4)_3$	0.03	0.03
Detergent	0.003	0.003
Suspended solids	1.3	1.5
Totals	369.83	423.03

It is conceivable that all wastewater sludges would be dewatered and disposed of as a single filter cake. This is an attractive idea from the point of view of disposal problems. However, complex chemical interactions among components of the sludge need to be investigated.

TABLE 57. CHARACTERISTICS OF SCRUBBER SLUDGE GENERATED IN COAL-FIRED POWER PLANTS (82)

Type SO_2 Control	Feed Coal Sulfur Content	Feed Coal Ash Content	Sludge Composition - Dry Basis (wt. %) Mg/D/MW	$CaSO_3 \cdot \frac{1}{2}H_2O$	$CaSO_4 \cdot 2H_2O$	$CaCO_3$	Flyash	Solids Content After Dewatering
Limestone Injection Wet Scrubber	3.8%	12%	2.05	10	40	5	45	50
Lime Scrubber	3.7%	14%	1.82	94	2	0	4	50
Tail-end Limestone Scrubber	3.5%	15%	2.55	50	15	20	15	35

3.7.6.6 Sludges from Steam and Power Generation

This sludge stems from flue gas desulfurization of the coal-fired steam generation operation. The residue of a convential calcium scrubbing process (lime or limestone) is a slurry of mainly calcium sulfite. The slurry is thixotrophic even after dewatering. The quantity of sludge generated depends upon the type of control, the extent of control required and the load factor for the plant. Table 57 shows quantities of sludge generated and sludge characteristics for power plants using different types of sulfur dioxide control systems (81).

Since it has been assumed that the 150 Mw/day of electricity required to run the SRC plant will be purchased, the use of coal for utilities is limited to steam generation.

3.7.7 Steam Generation

The coal-fired steam generation module will produce 66 Mg/day of bottom ash and 36.1 Mg/day of fly ash. As far as solid waste disposal practices are concerned the distinction is made because fly ash can contribute serious pollution problems in the form of leachates or fugitive dusts if not handled properly. Table 58 estimates the composition of fly ash from average and maximum U.S. coals.

Bottom ash is recovered from the dry bottom boiler and falls into a hopper filled with water. The ash and water slurry is mixed with the fly ash. The mixture may be piped to settling ponds or dewatered and hauled off-site for disposal. If settling ponds are used impervious liners (e.g., bentonite) may be required. The trace elements tend to form insoluble compounds which, together with solids in

TABLE 58. COMPOSITION OF FLY ASH FROM AVERAGE AND MAXIMUM U.S. COALS

Name	Con. (μg/g)	Conc. (μg/g)	Arithmetic mean	IL, IN, Western KY	AZ, CO, UT, NM	KY, Southern Illinois
Aluminum	79000.	$1.1x10^5$	60900			67000
Antimony	15.	35.		12	14	10
Arsenic	120.	385.	27	120	130	141
Barium	2500.	5000.		450		1700
Beryllium	11	24	6	3-17	5	3-17
Bismuth						2
Boron	385.	840.	366	250-3000[a]		1750
Bromine	32.	72.				
Cadmium	71.	340.	3	80-160		
Calcium	32000.	71000.	43000			17200
Cesium	14.	24.				18
Chlorine	130.	220.		5-50	50	
Chromium	150.	350.	126	310-500[a]		160
Cobalt	100.	250.	17	41-60		37
Copper	100.	270.	89	100-400[a]	280	367
Europium	2.5	4.1				
Fluorine	130.	270.	345[a]	10-100		
Gallium	24.	38.				70[a]
Germanium	50.	110.				135[a]
Hafnium	6.5	9.5				
Iron	74000	$1.6x10^5$	63000			100000
Lanthanum	62.	98.				33
Lead	130	650	52	80-200	10	210
Lithium	300	670				
Magnesium	6720	1700	9000			8600
Manganese	250	970	202	290-500		321
Mercury	0.075	0.36	3	0.2		0.06
Molybdenum	120	280		118	54	350[a]
Nickel	130	420	82	500		666
Niobium						10
Phosphorus	1000	1500	2200[a]			500
Potassium	16000.	36000.	10800.			16000
Rubidium	220.	800.				380.
Scandium	24.	40.				
Selenium	64.	170.	16.	25	73	24
Silicon	$1.4x10^5$	$1.7x10^5$	$2.38x10^5$			$3.0x10^5$
Silver						3-5
Sodium	$1.8x10^4$	$9.5x10^4$	9600			6400
Strontium	720.	1600.				300

(continued)

TABLE 58. (continued)

Name	Con. (μg/g)	Conc. (μg/g)	Arithmetic mean	IL, IN, Western KY	AZ, CO, UT, NM	KY, Southern Illinois
Tellurium	0.25	0.3		1-10[a]		1-ca.10
Thallium	23	23		40-100[a]		70
Thorium	35.	76.				20
Tin	2	5.				
Titanium	4200.	9100.	5400	6080		3480
Tungsten	3.6	4.1				5[a]
Uranium	16.	58.				18
Vanadium	310.	600.	212	440		307
Ytterbium	3.6	4.7				
Zinc	1900	23000	230	740-5900	360	2200
Zirconium	140.	275.				100

the suspension, will tend to fill and seal the pore space in underlying soils. Therefore, the rate of movement of leachate would decrease over an extended period of time. Good disposal practices, however, would probably require liners nevertheless.

The organic composition of fly ash has not been quantified but considerable danger may exist. PAH are readily adsorbed to particles having a diameter of less than 0.04 microns but are not readily eluted from them. Release in the presence of appropriate solvents becomes more rapid and greater in extent. Polycyclic organic matter detected in the atmosphere is exclusively associated with particulate matter, especially fly ash. Most data indicate that more than 75 percent of the benzo(a)pyrene associated with particles is associated with particles less than 5 microns in diameter (83). These particulates easily move into the lung in inspired air and are capable of loading in the alveolar region. The well documented experience of chimney sweeps in England in the 1600's shows the possible hazards of coal soot and fly ash.

3.7.8 Hydrogen Generation

One of the large volume solids to be disposed of in the SRC plant is the gasifier slag; this has been estimated at 92 Mg/day (40% water) (6).

The current design specifications for the treatment of the slag require that it be crushed, slurried with water and de-ashed. It is anticipated that the waste will be disposed of in the strip mine. It is thought that the waste will behave similarly to bottom ash from coal-fired power plants, and consequently will not leach (61). This is an area which requires investigation via laboratory leachate studies.

One interesting possibility for disposal of some of the other hazardous solid wastes would be encapsulation in the slag. The possibility of injecting dried solids into the molten slag should be investigated. The estimated composition of the slag is found in Table 59.

TABLE 59. ESTIMATED INORGANICS IN GASIFIER SLAG

Name	Estimated Slag Composition ($\mu g/g$) Average	Maximum
Lead	20.	100.
Manganese	97	370
Mercury	0.0093	0.0045
Nickel	42.	270.
Potassium	4100.	9000.
Rubidum	56.	200.
Selenium	7.2	19.
Silicon	43900	48200
Strontium	230.	490.
Sulfur	18000.	30000.
Titanium	450.	2000.
Zinc	180.	2700.
All Arithmetic means above		

4.0 PERFORMANCE AND COST OF CONTROL ALTERNATIVES

4.1 Procedures for Evaluating Control Alternatives

This section presents a comprehensive survey of the currently available environmental control technology alternatives applicable for installation on commercial SRC systems, and discusses the relative effectiveness of these control technologies in limiting emissions to the environment. Economic and energy considerations of these technologies are also presented.

The procedure utilized in the evaluation of each of the control technology alternatives consists of the following steps:

- Statement of Control Technology. A statement of the control technology to be considered is made, including the purpose and applicability of the technology.

- Definition of Control Technology. A description of the control technologies is made in the Appendices. This description includes the function, design and operational criteria.

- Identification of Relative Technology Impact. An evaluation of the relative efficiency and effectiveness to perform the intended environmental control function is included in the Appendices. This assessment provides the degree of control exhibited by the device, the parameter controlled, the amount of variability in equipment performance, and other criteria.

This section emphasizes the SRC-II (liquid) process and its applicable control technology needs; however, where necessary, SRC-I process or control technology needs are identified separately at the end of each major emission category description.

Subsequent to identification of applicable alternatives for control and disposal of air emissions, water effluents, solid wastes, and toxic substances generated by operation of SRC systems (in subsections 4.2-4.5), the most effective control alternatives are summarized in subsection 4.6. Evaluations of control alternative effectiveness are based on the following:

- Available SRC waste stream characteristics
- Effectiveness of control alternatives
- Commercial availability of control alternatives
- Review of SRC conceptual plant designs
- Engineering judgement

Section 4.0 concludes with a discussion of the feasibility of zero aqueous discharge (ZAD) for SRC systems (subsection 4.7), an overview of regional characteristics which can influence control technology selection (subsection 4.8), and a relative comparison of cost and energy considerations for some of the control alternatives considered.

4.2 Air Emission Control Alternatives

Air emissions associated with the operations and auxiliary processes comprising SRC systems are shown in Figure 51. In addition to the continuous emissions shown in the figure, vapor discharges will result from releases by pressure letdown valves, accidental leaks and during equipment main-

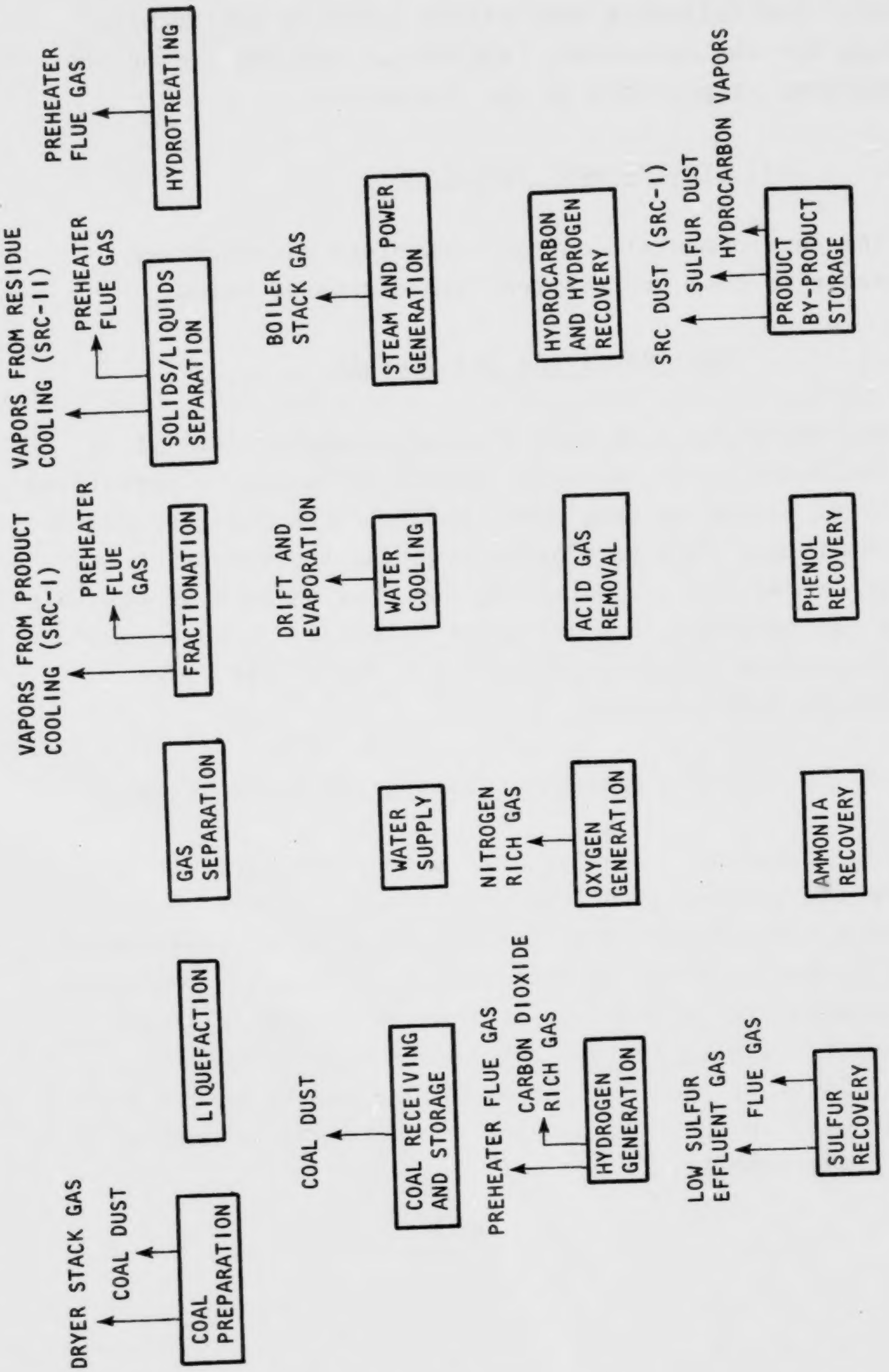
COAL PREPARATION
DRYER STACK GAS
COAL DUST
LIQUEFACTION
GAS SEPARATION
FRACTIONATION
VAPORS FROM PRODUCT COOLING (SRC-I)
PREHEATER FLUE GAS
SOLIDS/LIQUIDS SEPARATION
VAPORS FROM RESIDUE COOLING (SRC-II)
PREHEATER FLUE GAS
HYDROTREATING
PREHEATER FLUE GAS
COAL RECEIVING AND STORAGE
COAL DUST
WATER SUPPLY
WATER COOLING
DRIFT AND EVAPORATION
STEAM AND POWER GENERATION
BOILER STACK GAS
HYDROGEN GENERATION
PREHEATER FLUE GAS
CARBON DIOXIDE RICH GAS
OXYGEN GENERATION
NITROGEN RICH GAS
ACID GAS REMOVAL
HYDROCARBON AND HYDROGEN RECOVERY
SULFUR RECOVERY
LOW SULFUR EFFLUENT GAS
FLUE GAS
AMMONIA RECOVERY
PHENOL RECOVERY
PRODUCT BY-PRODUCT STORAGE
SRC DUST (SRC-I)
SULFUR DUST
HYDROCARBON VAPORS

Figure 51. Air emissions discharged from SRC systems

tenance. The following subsections identify applicable controls for the emissions. Additional information on the alternatives is provided in the Appendices.

4.2.1 Coal Pretreatment Operation

The environmental control technology alternatives applicable to coal pretreatment are discussed below.

4.2.1.1 Coal Receiving and Storage

Air emissions from coal storage primarily consist of fugitive dusts. Air emission control technology alternatives consist of either wetting down the coal with water sprays or an asphalt-type liquified product during the receiving and storage operation, or containing the coal as much as possible within the confines of a permanent structure. Confinement appears to have limited applicability due to the large quantity of coal involved.

4.2.1.2 Coal Crushing, Cleaning and Pulverizing

Coal crushing, cleaning, and pulverizing activities involve the mechanical sizing and cleaning of the coal. Baghouses and cyclones are considered the most viable means of particulate control in coal sizing processes. Two alternate systems are available. In some instances, a single baghouse (or fabric filter) may be adequate to control dusts. In other applications a cyclone may be needed prior to baghouse, in order to provide adequate and economical particulate removal.

4.2.1.3 Coal Drying

Coal drying utilizes a flow dryer to reduce feed coal moisture content. The fuel utilized is normally a low sulfur fuel, i.e., natural gas. It is assumed that SNG produced by the SRC system will be fired in the dryer. The major air emissions to be controlled from coal drying are particulate matter from fuel combustion. These emissions may be best controlled in dry or wet cyclone separators, or baghouses. Wet scrubbing devices using self- or mechanically-induced water sprays, such as venturi scrubbers may effectively be utilized if exhaust gas temperatures exceed the allowable limit for cyclone separators or filter baghouses. The selection of the recommended control alternative will be dependent on the type of fuel utilized, and the type and quantity of emission vented to the atmosphere. An in-depth description of particulate control technology is provided in the Appendices.

4.2.1.4 Slurry Mixing

The dried and crushed coal is mixed with recycle solvent (SRC-I) or recycle slurry (SRC-II), to form a coal/slurry mixture which is pumped to the coal liquefaction operation. There are no continuous air emissions from this process, although fugitive vapor emissions from the mixing equipment are anticipated. No control technology is required for normal operation.

4.2.2 Coal Liquefaction Operation

The anticipated air emissions from the coal liquefaction operation are flue gases from the slurry preheater. These emissions may be characterized by the fuel type utilized, which in turn will determine the degree and extent of air emission control technology required. Presently, it is expected that SRC system-derived SNG will be utilized, thereby eliminating the need for control technology.

Air emissions from the liquefaction reactor consist of fugitive releases resulting from accidental leaks, pressure relief valve releases and poor equipment maintenance. The effective air emissions control technology likely to be employed is a flare system.

4.2.3 Separation

4.2.3.1 Gas Separation Process

The three continuous process streams discharged from gas separation are: product slurry to the fractionator and slurry mixing tank; condensate to the fractionator; and acid gas to the acid gas removal module. No air emissions are produced since the system operates as a closed unit. However, fugitive hydrocarbon emissions may result from accidental leaks, pressure valve releases and poor equipment maintenance. The effective air control technology likely to be employed is flaring.

4.2.3.2 Solids/Liquids Separation Process

The air emissions from the solids/liquids separation process consist of flue gas from the residue dryers and hydrocarbon vapor discharges from pressure relief values. Pressure relief value discharges will be controlled via afterburner flare control technologies. Since the preheater is fired with system derived SNG, flue gas discharges require no control technology application.

4.2.4 Purification and Upgrading

4.2.4.1 Fractionation Process

Air emissions from fractionation consist of flue gas from the gas-fired preheater. Since the gas (SNG) is relatively pure, the flue gas emission requires no control technology application.

4.2.4.2 Hydrotreating Process

The major air emission is flue gas from the feed preheater. This gas is expected to contain no contaminants due to the nature of the preheater fuel utilized (system-derived SNG). However, fuel characteristics will determine control technology needs. At this time no air emission control technology application is required.

4.2.5 Auxiliary Processes

There are twelve auxiliary processes associated with SRC systems.

Each of these auxiliary processes is discussed separately in the following subsections.

4.2.5.1 Coal Receiving and Storage

Coal dust is the only air emission associated with this process. The same control methods used in coal pretreatment are applicable to coal receiving and storage and have been included in Section 4.2.1.

4.2.5.2 Water Supply

Water supply produces no emissions to air. No control technology is required for this auxiliary process.

4.2.5.3 Water Cooling

The air emission from cooling towers consists of entrained water droplets, called drift, in the cooling tower exhaust air. Cooling tower drift may contain trace compounds of material contained in the cooling water; however, it has been shown that 70 percent of these compounds and the drip mass generally settle out of the drift within 500 ft of the tower (6). Therefore, environmental impacts of cooling tower drift are reduced. There is no applicable air control technology other than to control the concentration of compounds contained in the cooling water, which will control drift emission characteristics.

4.2.5.4 Steam and Power Generation

The major air emission from this process is boiler stack gas. Depending on the type of fuel utilized, air emission control technology application will consist of particulate and sulfur dioxide control techniques.

If clean fuels such as system-derived SNG are used as fuel in boilers air emission control technology requirements are minimized. However, if coal is utilized as the fuel type both control of particulates and sulfur dioxide may be required.

4.2.5.5 Hydrogen Generation

Gaseous output streams from hydrogen production consist of the following:

- Acid gases from the amine stripping unit
- Flue gases from the gasification unit
- Carbon dioxide from the carbon dioxide scrubber unit
- Fugitive hydrocarbon releases from pressure valve releases and accidental discharges.

The acid gas stream from the amine stripping unit is a process stream, sent to sulfur recovery for further processing. The flue gas from the gasification unit is a primarily clean emission since the fuel utilized in the gasification unit is natural or synthetic gas; therefore, no air control technology is required. The carbon dioxide rich gas from the carbon dioxide scrubber is directly vented to the atmosphere. Fugitive hydrocarbon releases are controlled via flaring.

4.2.5.6 Oxygen Generation

A cryogenic air separation system consisting of air compression, cooling, and purification is employed for oxygen production. Since the process employs only atmospheric air, there are no air emissions except oxygen-stripped air-nitrogen, carbon dioxide, and inert gas. No air emission control technologies are required.

4.2.5.7 Acid Gas Removal

This auxiliary process involves the removal of acid gases such as hydrogen sulfide, carbonyl sulfide, carbon disulfide, mercaptans and carbon dioxide from the raw product gas. The processes may involve the removal of the sulfur compounds and carbon dioxide separately, or the removal of the sulfur compounds alone. Acid gas removal may be divided into two general categories:

- High temperature processes
- Low temperature processes.

High temperature processes require minimal product gas cooling before treatment, however, these types of processes are currently experimental and are not anticipated to be used at the SRC facilities. Low temperature processes require extensive cooling of the product gases before treatment. Table 60 lists a number of the commercially available low temperature acid gas removal processes.

Gaseous output streams from acid gas removal are sent to other auxiliary processes, namely hydrogen/hydrocarbon recovery and sulfur recovery. Air emissions from acid gas removal are limited to pressure valve releases and fugitive vapor discharges. Direct flare afterburners may be applied to control these discharges.

4.2.5.8 Sulfur Recovery

The air emission stream from a sulfur recovery process, such as Stretford consists of off-gas from the absorber unit which contains water vapor, carbon dioxide, oxygen, nitrogen,

TABLE 60. LOW TEMPERATURE ACID GAS REMOVAL PROCESSES (84)

Process Category	Process Name
Physical solvent	Selexol Fluor solvent Purisol Rectisol Estasolvan
Chemical solvent - Amine solvent	Monoethanolamine (MEA)* Diethanolamine (DEA) Triethanolamine (TEA) Methyldiethanolamine (MDEA) Glycol-amine Diisopropanolamine (DIPA) Diglycolamine (DGA)
- Alkaline salt solution	Caustic wash Hot potassium carbonate Catacarb Benfield Alkazid Lucas
- Ammonia solution	Chemo Frenn Collins

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*The monoethanolamine (MEA) process has been considered for acid gas removal in process descriptions presented in Section 2.

and trace amounts of hydrogen sulfide, carbon monoxide, ammonia, and oxides of nitrogen. The trace emissions may require combustion in a direct-fired afterburner as an air emission control technology alternative.

4.2.5.9 Hydrogen/Hydrocarbon Recovery

The air emissions from the process are negligible, consisting of fugitive pressure relief valve emission and vapor losses. Flares are utilized to control intermittent pressure relief valve releases.

4.2.5.10 Ammonia Recovery

Ammonia recovery produces no continuous emissions to air. No air emission control technology applications are required.

4.2.5.11 Phenol Recovery

Phenol recovery produces no continuous emissions to air. Therefore, no air emission control technology applications are required.

4.2.5.12 Product/By-Product Storage

SRC systems produce a large number of products and by-products which are stored on-site. The air emissions from these facilities consist of fugitive vapor losses. Application of vapor loss controls, such as a solid cover, floating roof or vapor recovery system to product and by-product storage vessels should minimize vapor losses (6).

Storage of solid products and by-products, namely SRC-I solid product and by-product sulfur, produces particulate emissions. Techniques used to control dust emissions from coal piles are applicable.

4.3 Water Effluent Control Alternatives

Sources of water effluents in SRC systems are identified in Figure 52. Discharges due to leaks and equipment maintenance are possible, but not included in the figure. The following subsections identify applicable treatment for the water effluents, with additional detail provided in the Appendices.

4.3.1 Coal Pretreatment Operation

The wastewater discharges from the coal pretreatment operation are discussed according to the component processes.

4.3.1.1 Coal Crushing, Cleaning and Pulverizing

The major source of wastewater from this area is the coal cleaning process. Coal washing involves working the coal with water to remove impurities. The wastewater from the process is combined with coal pile runoff and sent to a settling pond to allow for the sedimentation of suspended particles. The clarified waters are then returned to the operation for reuse.

4.3.1.2 Coal Drying and Slurry Mixing

There are no wastewater discharges from these processes, hence, application of control technology is not required.

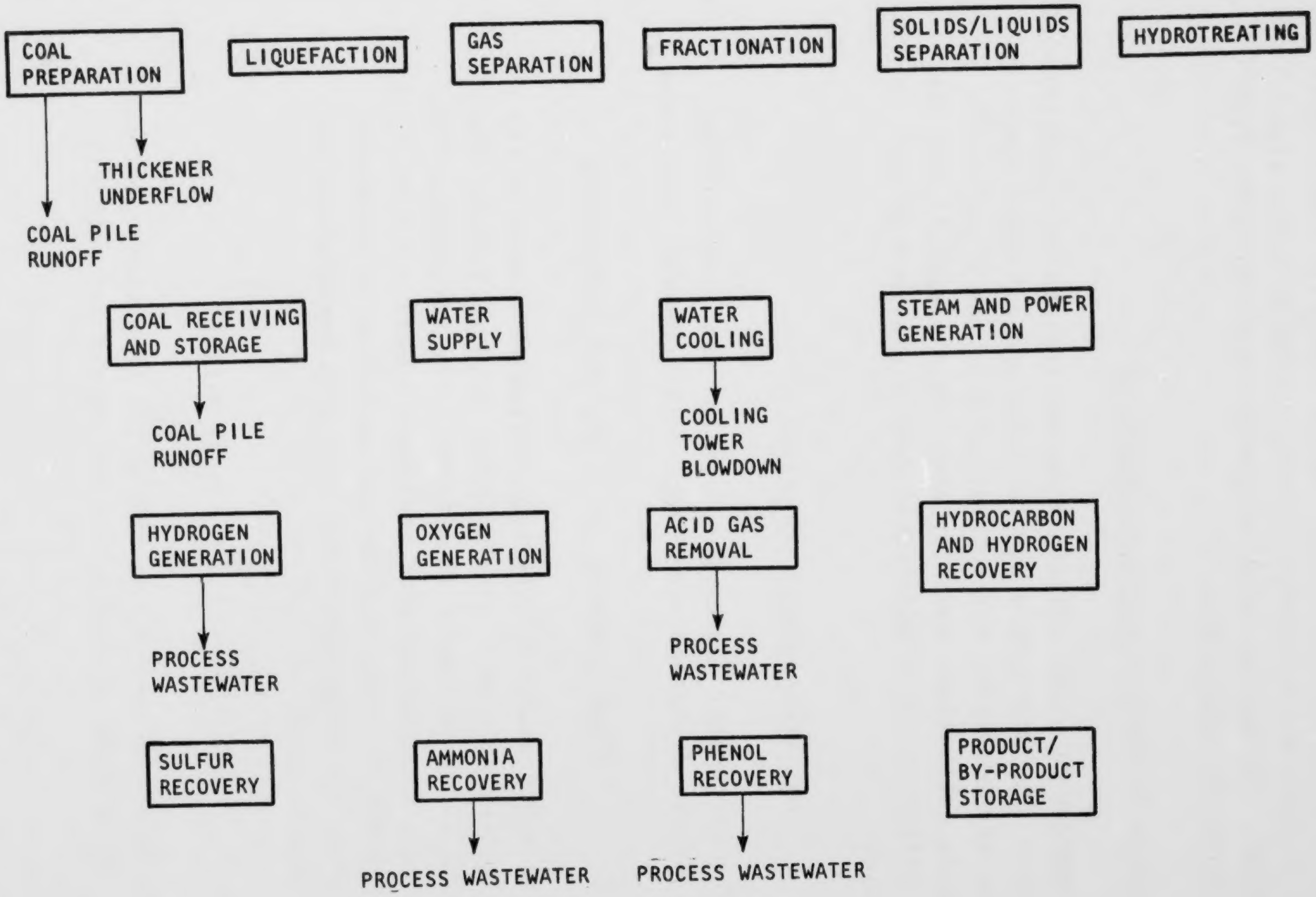
COAL PREPARATION
THICKENER UNDERFLOW
COAL PILE RUNOFF
LIQUEFACTION
GAS SEPARATION
FRACTIONATION
SOLIDS/LIQUIDS SEPARATION
HYDROTREATING
COAL RECEIVING AND STORAGE
COAL PILE RUNOFF
WATER SUPPLY
WATER COOLING
COOLING TOWER BLOWDOWN
STEAM AND POWER GENERATION
HYDROGEN GENERATION
PROCESS WASTEWATER
OXYGEN GENERATION
ACID GAS REMOVAL
PROCESS WASTEWATER
HYDROCARBON AND HYDROGEN RECOVERY
SULFUR RECOVERY
AMMONIA RECOVERY
PROCESS WASTEWATER
PHENOL RECOVERY
PROCESS WASTEWATER
PRODUCT/ BY-PRODUCT STORAGE

Figure 52. Sources of wastewater effluent discharges in SRC systems

4.3.2 Coal Liquefaction Operation

The coal liquefaction operation is a closed system from which no aqueous effluents are discharged, therefore no wastewater control technology alternatives are required.

4.3.3 Separation

4.3.3.1 Gas Separation Process

The gas separation process is a closed system operation and effluents are limited to accidental material leaks; therefore, wastewater control technology alternatives are not required.

4.3.3.2 Solids/Liquids Separation Process

The solids/liquids separation process produces no aqueous discharges. No wastewater control technology alternatives are required for this process.

4.3.4 Purification and Upgrading

4.3.4.1 Fractionation Process

The major aqueous process effluent emitted from the fractionation process is steam ejector condensate. This condensate contains significant amounts of organics which require treatment. The fractionation process wastewater discharge is combined with similar condensate steam and sent to the plant's wastewater treatment system.

4.3.4.2 Hydrotreating Process

The hydrotreating process involves the reaction of raw hydrocarbon products with hydrogen to remove additional sulfur and other contaminants. This process produces a significant wastewater discharge. This effluent stream is combined with other condensates prior to treatment. The wastewater treatment system requires free and emulsified oil removal units, phenol, hydrogen sulfide, and ammonia stripping units. After treatment, a portion of the water is returned to the process for reuse, while the rest is sent to tertiary treatment for further processing.

4.3.5 Auxiliary Processes

4.3.5.1 Coal Receiving and Storage

The wastewater discharge from the process consists of coal pile runoff resulting from the weathering of the stored coal.

The water emission control alternatives consist of either controlling the emission prior to the occurrence, or containing the discharges. In the first instance the stored coal may be kept within the confines of a permanent structure to eliminate or reduce the amount of weathering of the coal during storage. This will reduce or eliminate the major amount of coal pile runoff discharges. The practicality of using enclosure is limited due to the quantity of coal involved.

The suggested control alternative for coal pile runoff from unenclosed storage areas involves the collecting (via a drainage system) of the runoff, and combining it with coal cleaning wastewaters prior to disposal in a settling pond.

4.3.5.2 Water Supply

No wastewater discharges are associated with the water supply process. Therefore, no control technology is required.

4.3.5.3 Water Cooling

The cooling system consists of a cooling tower or series of towers, a recirculating cooling water system, and a series of treatment units to process blowdown water.

4.3.5.4 Steam and Power Generation

The wastewater discharge system consists of boiler and cooling tower blowdown which is treated in conjunction with the cooling tower blowdown.

4.3.5.5 Hydrogen Generation

The major wastewater streams from hydrogen generation consist of:

- Sour and foul water discharge

- Purge wastewater stream from amine scrubbing unit.

These wastewater streams are combined with other effluents and directed to the plant wastewater treatment facility.

4.3.5.6 Oxygen Generation

Oxygen generation is a purely mechanical process involving no water intake or discharge stream; therefore, no wastewater control technology is required.

4.3.5.7 Acid Gas Removal

The wastewater stream discharges from acid gas removal are absorber regenerator blowdown and intermittently discharged filter backwash. These streams will be directed to the wastewater treatment plant.

4.3.5.8 Sulfur Recovery

Sulfur recovery in SRC systems is accomplished via the application of the Stretford sulfur recovery process. There is no wastewater discharged from this process, therefore, no wastewater emission control technology alternatives are required.

4.3.5.9 Hydrogen/Hydrocarbon Recovery

The only wastewater discharge from this process is the water and ammonia sidestream from the light oil distillation. This stream flows directly into the ammonia recovery process, therefore, no wastewater treatment alternatives are required.

4.3.5.10 Ammonia Recovery

Ammonia recovery involves the removal of ammonia in wastewater prior to final treatment. The process involves the following steps:

- pH is adjusted to approximately 11.0 by addition of calcium oxide (lime).

- The wastewater stream is clarified to remove excess lime.

- The discharged streams are passed through a series of air contact packed towers which allows for the removal of ammonia and discharge to ammonia recovery and storage areas.

Stripped wastewater is discharged to the wastewater treatment plant.

4.3.5.11 Phenol Recovery

The phenol recovery process involves the following series of steps:

- Adjustment of pH of the wastewater stream to approximately 4.0 by addition of hydrochloric acid.
- Contact with naphtha to extract phenol.
- Phenol/naphtha stream is directed to a fractionation tower where the naphtha is recovered and recycled back to the process.
- Collected phenol is sent to on-site storage facilities.

The low phenol process wastewater discharge is directed to the plant wastewater treatment facility.

4.3.5.12 Product/By-Product Storage

No wastewater effluent discharges are associated with product and by-product storage facilities, hence, no control technology application is required.

4.4 Solid Waste Control Alternatives

A number of the processes and auxiliary processes employed in SRC systems discharge solid wastes. Figure 53 shows these sources. The following subsections identify applicable control/disposal practices for the solid wastes.

4.4.1 Coal Pretreatment Operation

Refuse from cleaning is generated as solid waste. Land disposal without pretreatment is the most applicable alternative. Minefilling coal refuse may be preferable to development of a landfill site, depending on cost considerations, including the proximity of the mine-mouth to the SRC facility.

4.4.2 Coal Liquefaction

No solid waste discharges are associated with this operation. Therefore, application of control/disposal alternatives is not required.

4.4.3 Separation

4.4.3.1 Gas Separation Process

No solid wastes are discharged from the gas separation process.

4.4.3.2 Solids/Liquids Separation Process

The solids/liquids separation process generates solids in the form of filter cake in SRC-I systems, or mineral residue in SRC-II systems. Existing information on the characteristics of these materials is limited, however,

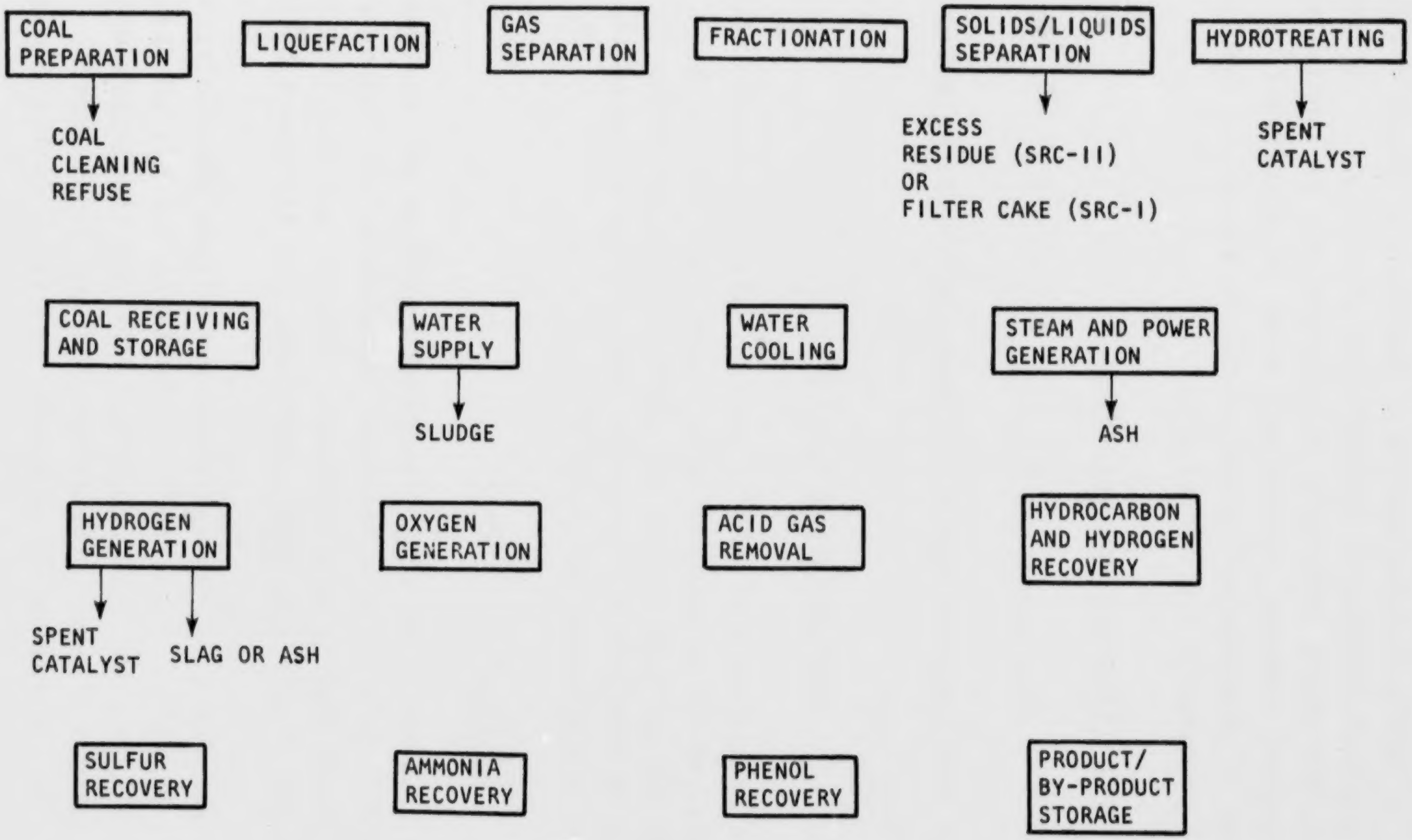
COAL PREPARATION
COAL CLEANING REFUSE
LIQUEFACTION
GAS SEPARATION
FRACTIONATION
SOLIDS/LIQUIDS SEPARATION
EXCESS RESIDUE (SRC-II) OR FILTER CAKE (SRC-I)
HYDROTREATING
SPENT CATALYST
COAL RECEIVING AND STORAGE
WATER SUPPLY
SLUDGE
WATER COOLING
STEAM AND POWER GENERATION
ASH
HYDROGEN GENERATION
SPENT CATALYST
SLAG OR ASH
OXYGEN GENERATION
ACID GAS REMOVAL
HYDROCARBON AND HYDROGEN RECOVERY
SULFUR RECOVERY
AMMONIA RECOVERY
PHENOL RECOVERY
PRODUCT/ BY-PRODUCT STORAGE

Figure 53. Sources of solid wastes in SRC systems

efforts to better understand the properties of these solids are underway as described elsewhere in this report. It is expected that these materials will ultimately be landfilled or minefilled, however, additional study is required to determine if predisposal treatment of the solids or special disposal procedures are necessary.

4.4.4 Purification and Upgrading

4.4.4.1 Fractionation Process

The fractionation operation does not discharge solid wastes.

4.4.4.2 Hydrotreating Process

The hydrotreating process periodically discharges spent catalysts, which is replaced with fresh catalysts. This material may be returned to the manufacturer for regeneration, or landfilled, if proper precautions to prevent groundwater contamination are taken.

4.4.5 Auxiliary Processes

Of the twelve auxiliary processes used in SRC systems, only water supply, steam and power generation and hydrogen generation discharge solid wastes. Control and disposal options for solids from these processes are discussed below.

Conditioning of raw water for use within the SRC system produces a sludge. Available alternatives for sludge disposal are landfilling and landspreading. For the sludge produced by raw water treatment, the former alternative is more likely. Landspreading is generally practiced with biological sludges such as those generated by industrial or municipal wastewater treatment plants.

If coal is consumed as fuel for steam and power generation significant quantities of bottom ash are produced. Ash may be landfilled in suitable locations without predesigned treatment.

The hydrogen generation process also produces ash from the mineral matter present in the gasifier feed materials (residue or filter cake from solids/liquids separation and/or coal). The ash may be produced as slag (fused ash) depending on the operating temperature of the gasifier. Gasifier ash (or slag) can be landfilled with ash from steam and power generation. The shift converter unit of the hydrogen generation process uses a catalyst. Periodically spent catalysts will be removed and replaced with fresh ones. The spent catalyst can be either returned to the manufacturer for regeneration or landfilled, although predisposal treatment may be required.

4.5 Toxic Substances Control Alternatives

Toxic substances in SRC systems are primarily associated with products and by-products. Best available characterizations of toxic substances in products and by-products are presented in subsection 3.4. Toxics may enter the environment as a result of leaks or materials spills within processes such as gas separation, fractionation, solids/liquids separation and hydrotreating or during storage, distribution and utilization of the products and by-products. There are a number of engineering practices which, if followed, act as preventive measures to minimize the risk of material spills. The following are some key practices in preventing material spills:

- Awareness of and adherence to applicable construction codes

- Detailed corrosion engineering appraisals

- Regular inspection of storage vessels

- Quick response preventive maintenance

- Installation and periodic testing of safety relief valves.

As an additional measure a contingency plan defining procedures to be followed in the event a spill or leak occurs should be developed and distributed to plant personnel. A material spill contingency plan addresses four areas:

- Spill detection
- Spill containment
- Material recovery
- Material disposal

Material spills prevention and contingency plans are discussed in detail in the Appendices.

4.6 Summary of Most Effective Control Alternatives

Subsections 4.6.1-4.6.4 summarize recommended control alternatives for control of air emissions, water effluents, solid wastes and toxic substances present in SRC products.

4.6.1 Emissions Control

Suggested control alternatives for controlling air emissions from SRC systems are given in Table 61. Final selection of controls for an actual facility should be based on regional, regulatory, economic and site-specific considerations. Accidental vapor discharges may occur due to leaks caused by mechanical failure of equipment. Accidental release technology is not addressed in Table 61 but is discussed in the Appendices.

4.6.2 Effluents Control

Table 62 is a summary of preferred control alternatives for treatment of water effluents from SRC systems. In addition to the discharges shown in the table accidental leaks may occur. Accidental leaks and spills technology are considered in the Appendices.

Runoff from coal preparation, receiving and storage is combined with thickener underflow from coal preparation and sent to a tailings pond. Overflow from the thickener is recycled to the coal cleaning process.

Cooling tower blowdown is treated to remove dissolved solids. Lime softening, ion exchange and reverse osmosis are processes used to reduce dissolved solids content. Selection of sidestream treatment should be based on more detailed analysis of regional, economic, regulatory and site-specific factors. The treated water is then discharged to receiving waters.

The remaining process wastewater discharges are combined during treatment in the plant's main wastewater treatment

TABLE 61. SUMMARY OF AIR EMISSIONS CONTROL TECHNOLOGY APPLICABILITY TO SRC SYSTEMS

Operation/Auxiliary Process	Air Emissions Discharged	Preferred Control Technology Applications
Coal pretreatment	Coal dust	(1) Spray storage piles with water or polymer. (2) Cyclones and baghouse filters for control of dust due to coal sizing.
	Particulate laden flue gas from coal dryers	(1) Cyclones and baghouse filters. (2) Wet scrubbers such as venturi.
Liquefaction	Preheater flue gas	(1) If other than clean gas, scrub for sulfur, nitrogen, and particulate components.
	Pressure letdown releases	(1) Flaring*
Separation		
Gas separation	Pressure letdown releases	(1) Flaring*
Solids/liquids separation	Preheater flue gas	(1) If other than clean gas, scrub for sulfur, nitrogen, and particulate components.
	Particulate laden vapors from residue cooling (SRC-II)	(1) Cyclone and baghouse filter. (2) Wet scrubbers.
	Pressure letdown releases	(1) Flaring.*
Purification and Upgrading		
Fractionation	Preheater flue gas	(1) If other than clean gas, scrub for sulfur, nitrogen, and particulate components.
	Particulate laden vapors from product cooling (SRC-I)	(1) Cyclone and baghouse filter (2) Wet scrubbers
	Pressure letdown releases	(1) Flaring*

(continued)

TABLE 61. (continued)

Operation/Auxiliary Process	Air Emissions Discharged	Preferred Control Technology Applications
Hydrotreating	Preheater flue gas	(1) If other than clean gas, scrub for sulfur, nitrogen, and particulate components.
	Pressure letdown releases	(1) Flaring*
Coal receiving and storage	Coal dust	(1) Spray storage piles with water or polymer
Water supply	None	
Water cooling	Drift and evaporation	(1) No controls available - good design can minimize losses
Steam and power generation	Boiler flue gas	(1) Sulfur dioxide scrubbing with aqueous magnesium oxide solution
Hydrogen generation	Carbon dioxide rich gas	(1) None required
	Preheater flue gas	(1) If other than clean gas, scrub for sulfur, nitrogen, and particulate components.
Oxygen generation	Nitrogen rich gas	(1) None required
Acid gas removal	Pressure letdown releases	(1) Flaring*
Sulfur recovery	Flue gas	(1) If other than clean gas, scrub for sulfur, nitrogen, and particulate components.
	Low-sulfur effluent gas**	(1) Carbon adsorption (2) Direct-flame incineration (3) Secondary sulfur recovery
Hydrogen/hydrocarbon recovery	Pressure letdown releases	(1) Direct fired afterburner

(continued)

TABLE 61. (continued)

Operation/Auxiliary Process	Air Emissions Discharged	Preferred Control Technology Applications
Ammonia recovery	None	
Phenol recovery	None	
Product/by-product storage	SRC dust (SRC-I)	(1) Spray storage piles with water
	Sulfur dust	(1) Store in enclosed area
	Hydrocarbon vapors	(1) Spills/leaks prevention

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*Collection, recovery of useful products and incineration may be more appropriate.

**A secondary sulfur recovery process may be necessary to meet specified air emission standards.

TABLE 62. SUMMARY OF WATER EFFLUENTS CONTROL TECHNOLOGY APPLICABILITY TO SRC SYSTEMS

Operation/Auxiliary Process	Water Effluents Discharged	Preferred Control Technology Applications
Coal pretreatment	Coal pile runoff	(1) Route to tailings pond
	Thickener underflow	(1) Route to tailings pond
Liquefaction	None	
Separation		
Gas separation	None	
Solids/liquids separation	None	
Purification and Upgrading		
Fractionation	None	
Hydrotreating	None	
Coal receiving and storage	Coal pile runoff	(1) Route to tailings pond
Water supply	None	
Water cooling	Cooling tower blowdown	(1) Sidestream treatment (electrodialysis, ion exchange or reverse osmosis) permits discharge to receiving waters
Steam and power generation	None	
Hydrogen generation	Process wastewater	(1) Route to wastewater treatment facility*
Oxygen generation	None	
Acid gas removal	Process wastewaters	(1) Route to wastewater treatment facility*

(continued)

TABLE 62. (continued)

Operation/Auxiliary Process	Water Effluents Discharged	Preferred Control Technology Applications
Sulfur recovery	None	
Hydrogen/hydrocarbon recovery	None	
Ammonia recovery	Process wastewater	(1) Route to wastewater treatment facility*
Phenol recovery	Process wastewater	(1) Route to wastewater treatment facility*
Product/by-product recovery	None	

---

*Two alternatives for the wastewater treatment facility are shown in Figure 54.

plant. Two alternative wastewater treatment schemes are considered applicable to treatment of the water discharges. These schemes are described in Figure 54. Sludges produced by wastewater treatment may be landfilled.

4.6.3 Solid Wastes Control

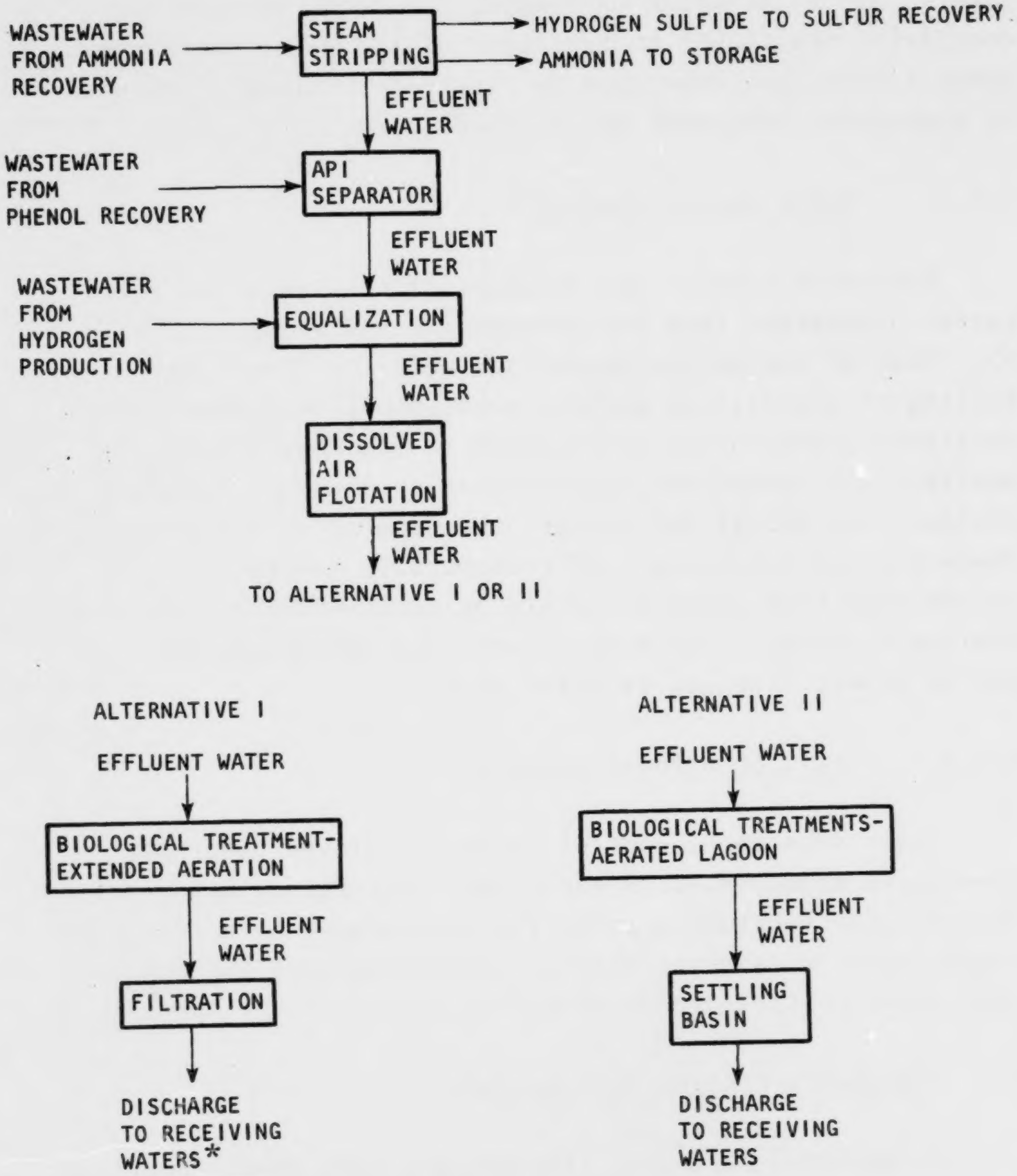
Preferred control and disposal alternatives for solid wastes discharged from SRC systems are summarized in Table 63. Most of the solids appear suitable for direct landfilling or minefilling without predisposal treatment. Spent catalysts produced may be returned to the manufacturer for analysis and subsequent regeneration or disposal. Mineral residue from SRC-II and filter cake from SRC-I are not well characterized materials. If economically feasible, it is recommended that these materials be gasified to recover available energy. The slag or ash produced by gasification may be safety disposed as solid waste.

4.6.4 Toxic Substances Control

Toxic substances control is best achieved by proper preventive measures, with additional contingency measures should toxic substances enter the environment as a result of vapor leaks or material spills. Considerations for toxic substances control are described in detail in the Appendices.

4.7 Multimedia Control Alternatives

No multimedia control alternatives have been identified as applicable to SRC systems. However, the concept of zero aqueous discharge (ZAD) wastewater treatment does represent an attempt to integrate various discharges for combined treatment within one wastewater treatment system.


WASTEWATER FROM AMMONIA RECOVERY
STEAM STRIPPING
HYDROGEN SULFIDE TO SULFUR RECOVERY
AMMONIA TO STORAGE
EFFLUENT WATER
WASTEWATER FROM PHENOL RECOVERY
API SEPARATOR
EFFLUENT WATER
WASTEWATER FROM HYDROGEN PRODUCTION
EQUALIZATION
EFFLUENT WATER
DISSOLVED AIR FLOTATION
EFFLUENT WATER
TO ALTERNATIVE I OR II
ALTERNATIVE I
EFFLUENT WATER
BIOLOGICAL TREATMENT-EXTENDED AERATION
EFFLUENT WATER
FILTRATION
DISCHARGE TO RECEIVING WATERS*
ALTERNATIVE II
EFFLUENT WATER
BIOLOGICAL TREATMENTS-AERATED LAGOON
EFFLUENT WATER
SETTLING BASIN
DISCHARGE TO RECEIVING WATERS

*Discharge preceded by tertiary treatment as required.

Figure 54. Two wastewater treatment alternatives applicable to SRC systems

TABLE 63. SUMMARY OF SOLID WASTES CONTROL TECHNOLOGY APPLICABILITY TO SRC SYSTEMS

Operation/Auxiliary Process	Solid Wastes Discharged	Preferred Control Technology Applications
Coal pretreatment	Refuse	(1) Landfill (2) Dumping (minefill)
Liquefaction	None	
Separation		
Gas separation	None	
Solids/liquids separation	Excess residue (SRC-II) or filter cake (SRC-I)	(1) Gasification to recovery energy content followed by disposal (landfill or minefill)
Purification and Upgrading		
Fractionation	None	
Hydrotreating	Spent catalyst	(1) Return to manufacturer for regeneration
Coal receiving and storage	None	
Water supply	Sludge	(1) Dewatering followed by landfilling
Water cooling	None	
Steam and power generation	Ash	(1) Landfill (2) Dumping (minefill)
Hydrogen generation	Ash or slag	(1) Landfill (2) Dumping (minefill)

(continued)

TABLE 63. (continued)

Operation/Auxiliary Process	Solid Wastes Discharged	Preferred Control Technology Applications
Oxygen generation	None	
Acid gas removal	None	
Sulfur recovery	None	
Hydrogen/hydrocarbon recovery	None	
Ammonia recovery	None	
Phenol recovery	None	
Product/by-product storage	None	

ZAD options for SRC-II liquefaction are currently being investigated to determine their technical and economic feasibility (85). The following water treatment requirements are being addressed:

- Raw water treatment
- By-product recovery from system wastewaters
- Water treatment for the water cooling process
- Final wastewater treatment

The water management system is shown in Figure 55. Wastewater treatment options for the wastewaters from SRC system operations and water cooling process are summarized in Table 64.

Tentative conclusions of the work are that the zero discharge system is technically feasible but expensive. Installed capital costs total nearly $38 million, and annual costs (operating costs plus fixed costs such as maintenance, cost of financing the project, taxes and insurance) total $14 million. Putting these figures in perspective, the zero discharge system will add $0.87 to the cost of 0.16 cubic meter (one barrel) of the SRC-II product from a 7,950 cubic meter per day plant. Using a plant investment cost of $1 billion which is scaled from an Electric Power Research Institute estimate (6), the zero discharge system will add 3.8 percent to the cost of the plant.

4.8 Regional Considerations Affecting Selection of Alternatives

A number of factors should be considered when selecting control technology for SRC systems, including the following:

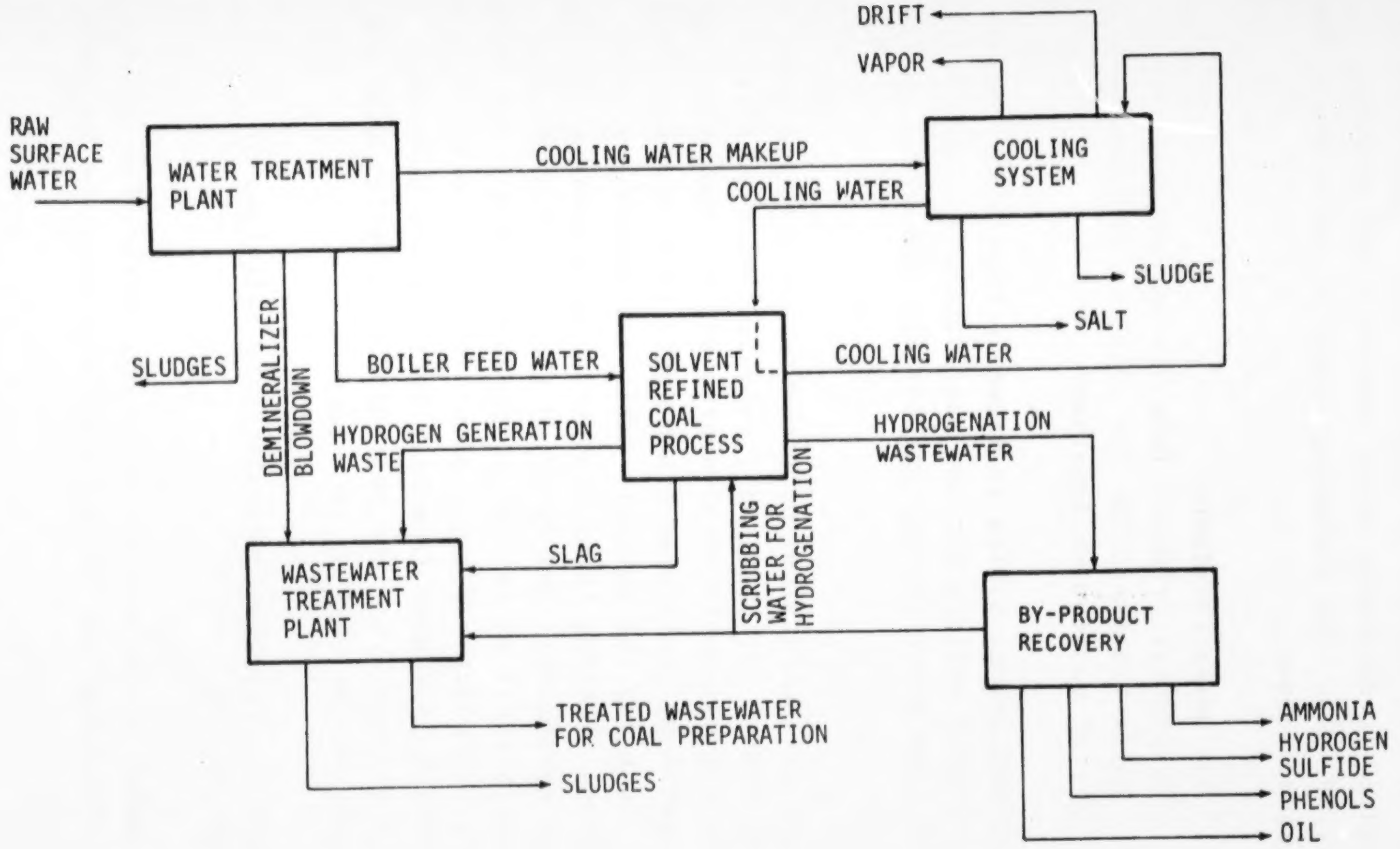

DRIFT
VAPOR
RAW SURFACE WATER
WATER TREATMENT PLANT
COOLING WATER MAKEUP
COOLING SYSTEM
COOLING WATER
SLUDGE
SALT
SLUDGES
DEMINERALIZER BLOWDOWN
BOILER FEED WATER
SOLVENT REFINED COAL PROCESS
COOLING WATER
HYDROGEN GENERATION WASTE
HYDROGENATION WASTEWATER
SCRUBBING WATER FOR HYDROGENATION
SLAG
WASTEWATER TREATMENT PLANT
BY-PRODUCT RECOVERY
TREATED WASTEWATER FOR COAL PREPARATION
SLUDGES
AMMONIA
HYDROGEN SULFIDE
PHENOLS
OIL

Figure 55. Zero discharge water management system for SRC-II

TABLE 64. SUMMARY OF WASTEWATER TREATMENT OPTIONS FOR SRC-II

Major Waste Stream	Pollutant	Treatment Method	Limitations	Applicable Concentration Range	Performance	Industry Usage	Relative Cost
Wastewater from SRC-II system operation	Tar and Oil	(1) Gravity separation	Does not remove emulsion	Primary treatment	Removes 60-99% floated oil	Common	Low
		(2) Centrifugation	High operations and maintenance costs	Secondary treatment		Common	High
		(3) Heating	High operating costs	Secondary treatment		Not practiced	Moderate
		(4) Precoat filtration	High operation and maintenance costs	Secondary treatment	5-20 mg/l	Common	Moderate
		(5) Coagulation or de-mistification with chemicals, followed by air flotation or settling	Addition of alum-forms sludge which are difficult to dewater	Secondary treatment	50-90% **Removal**	Common	Moderate
		(6) Biological treatment		Secondary treatment	Removal to 15/mg/l	Common	Moderate
	Phenols	(1) Stripping Processes		500 mg/l	5.240 mg/l	Common	Low
		(2) Incineration	High operations and maintenance costs, extensive corrosion problems.	7000 mg/l	Complete	Not practiced	High
		(3) Biological Treatment	High concentrations will upset plant operation	50-500 mg/l	99% Removal	Common	Low
		(4) Physical-Chemical Processes	Expensive	<50 mg/l	90-99% Removal	Common	Low
	Ammonia	(1) Stripping at pH of 10-11	Water adsorbs CO_2-may lead to scale formation		50-90% **Removal**	Extensive	Moderate
		(2) Biological nitrification	Nutrient may be required	<1250 mg/l	Removal to 2 mg/l	Extensive	Moderate
		(3) Ion exchange	High operations and maintenance costs		80-95% **Removal**	Not practiced	High

(continued)

TABLE 64. (continued)

Major Waste Stream	Pollutant	Treatment Method	Limitations	Applicable Concentration Range	**Performance**	Industry Usage	Cost
Wastewater From SRC-II system operation • Cooling Tower Blowdown 1550 kkg/day (1,710 TPD)	Sulfide	(1) Biological oxidation to sulfate			Complete oxidation	Common	Moderate
		(2) Stripping			50-90% **Removal**	Extensive	Moderate
	Suspended Solids	(1) Sedimentation			90-95% **Removal**	Extensive	Moderate
		(2) Chemical coagulation			95-99% **Removal**	Moderate	High
		(3) Filtration			95% **Removal**	Moderate	Moderate
		(4) Dissolved air flotation	Chemical addition may be required	Secondary treatment	75-95% **Removal**	Moderate	High
	pH Control	(1) Neutralization with chemicals	Cost depends on buffer capacity of waste		Neutral pH	Common	Low
	Dissolved Solids	(1) Concentration and evaporation		>50000 mg/l	Complete removal	Limited application desalination technology	High
		(2) Reverse osmosis	Efficiency depends on membrane condition		50-95% **Removal**	Limited application desalination technology	High
		(3) Distillation			60-90% **Removal**	Limited application desalination technology	High
	Hardness	(1) Softening	Sludges difficult to dispose			Common	Modera

- Applicable federal, state, and local legislation governing control/disposal practices
- Characteristics of the region proposed for locating an SRC facility
- Characteristics of the specific site selected for construction of the facility.

Applicable legal standards are discussed in Section 5.0, "Analysis of Regulatory Requirements and Environmental Impacts." This subsection overviews some of the regional characteristics which may influence selection of control methods for treating SRC system discharges. Subsection 5.8, "Siting Considerations for SRC Plants" provides additional detail on regional considerations from the aspect of evaluating potential locations for future SRC commercial facilities.

The primary concerns with selection of air emission control of alternatives are the physiographic characteristics of the region. Macro- and micro-climatic concerns include weather patterns, annual rainfall, water availability, annual temperature ranges and related climatic variables. These factors are important because, if, for example, the annual water supply is limited due to low rainfall or poor environmental water storage the selection of wet scrubbing devices may not be feasible. Temperature characteristics of a specified region could also affect selection of air emissions controls. For instance, an SRC facility located in EPA Region VII, which includes the states of Montana, Wyoming, Utah, Colorado and the Dakotas could encounter difficulties with operation and maintenance of water spray dust controls due to freezing conditions prevalent much of the year. For specific sites within EPA Region VIII detailed engineering evaluation could also show such alternatives to be impractical.

Regional climatic and physiographic characteristics are also important in selection of effluent and solid waste control/disposal methods. For example, both water availability and temperature variation within a region can affect selection of water effluent treatment. Insufficient water supply could require maximization of water reuse within the plant. A zero aqueous discharge wastewater treatment facility as discussed in subsection 4.7 may be necessary to meet constraints of water availability and demand. Temperature variations can influence reliability of operation of water effluent treatment alternatives, notably biological treatment methods. Regional soil geology is important in making solid waste disposal considerations. One such example is the proximity of local groundwater aquifers to proposed disposal sites. Some potential sites may be unacceptable for this reason. Others may require exercising special control/disposal alternatives to minimize the risk of contaminating aquifers.

Additional geographic characteristics which should be considered are concerned with soil type, soil texture, soil permeability and soil hydrologic conditions. These edaphic conditions will determine the suitability of landfilling and landfill site selection as a solid waste disposal alternative.

The selection, application and operation of pollution control alternatives must include any regional variances or considerations which may affect the control alternatives. The above description is only an example of each site application needing evaluation and assessment for the existing influencing parameters.

4.9 Summary of Cost and Energy Considerations

This section discusses economic aspects of the various environmental control technology alternatives cited in subsection 4.6. Considerations of energy requirements for the control alternatives are given in some instances, but are primarily made implicitly in estimates of annual operating costs. Data reported in this section are based on operation of a 7,950 m^3/day SRC-II facility as described in Section 2.0. Reported costs are in July, 1977 dollars. Supplemental data on cost estimation are included in the Appendices.

4.9.1 Air Emissions Control Alternatives

Subsection 4.6.1 specifies the following preferred air emissions controls for application in SRC systems:

- Utilization of sprays to control emissions of stored materials (coal, SRC-I, sulfur)
- Use of either wet scrubbers or cyclone/baghouse filter combinations to control particulates from the coal sizing and drying processes
- A flare system to control emissions attributable to pressure control releases within the system
- A sulfur dioxide scrubber to treat boiler stack gases from steam and power generation
- Three alternatives (carbon adsorption, direct-flame incineration and secondary sulfur recovery processes) to treat tail gas from the sulfur recovery auxiliary process.

Cost and energy considerations for these controls are described below.

Particulate emissions in the form of fugitive dust are associated with storage of coal, SRC-I product, and by-product sulfur. Annual operating and capital costs for two control alternatives, spraying the storage pile and enclosed storage, as applied to the broken coal storage pile in the coal pretreatment operation, are given in Table 65.

TABLE 65. COSTS OF CONTROL ALTERNATIVES FOR FUGITIVE DUST

Basis: 9,100 Mg - Broken Coal Storage Pile

	Operating Cost (Annual)	Capital Cost
Polymer coating	\$ 12,600-21,000	\$ 18,000
Enclosed storage		\$6-8 million

From the table it is evident that enclosed storage is not a cost effective control alternative, however, it may be used for storage of by-product sulfur to prevent contamination.

The raw coal stockpile, obviously too large for enclosure, also requires spraying. Material costs of polymer spraying the raw coal stockpile are approximately 7¢/m^2 of stockpile (84). The operating costs of spraying with a hydromulcher range from \$600 to 1000/day (84). Material costs for the raw coal pile (3.3×10^4 m^2) would be \$2,400 per application. An application every three days would result in a material cost of about \$240,000 per year with operating costs of \$180,000-300,000/year.

Table 66 summarizes the cost of alternatives for control of dust from coal sizing processes. Due to insufficient operating cost information for the cyclone/baghouse filter alternative, additional cost analysis as well as regulatory and siting considerations must be made prior to final selection of controls.

Baghouse filters and wet scrubbers are preferred alternatives for control of particulates in the coal dry stack gases. Table 67 shows cost and performance data applicable to these alternatives.

SRC production, like petroleum refining and chemical processing industries, must dispose of small quantities of continuous hydrocarbon waste gas streams from the process units such as the hydrogenation reactor, flash drum separators and the fractionation column. In case of accidental release due to equipment failure, large flows of gases must be disposed. The common practice of disposal is the use of a flare. Elevated combustion flare systems will be most applicable for the liquefaction plant, since large gas flows are involved. Air inspiration with steam will be utilized to achieve smokeless combustion (87).

Combustion in smokeless elevated flares is essentially complete with the CO_2 to CO to hydrocarbon ratio of stack gas being 100:4:0.002. On a dry basis, carbon monoxide levels would be 4,000 ppm and hydrocarbon levels would be only 2 ppm (88).

The amount of gases to be flared and the composition of these gases are assumed to be that of a refinery processing 7,950 m^3/day of oil. The stack height will be in the range of 33 to 100 meters depending upon the location of the plant

TABLE 66. COST OF TREATMENT ALTERNATIVES FOR CONTROL OF DUST FROM COAL SIZING (82,84,85)

Basis: Four units, each handling 1.8 m^3/sec with a grain loading of 6.5 mg/m^3 (8,646 ppm)

Treatment	Costs Capital[1] ($1000)	Operating[2] (Annual)	Efficiency	Emission After Treatment	Secondary Waste[3]
Cyclone & Baghouse	4,500 10,500	NA	99.9%	8.6 ppm	dust
Per unit	15,000				
Total	60,000				
Wet Scrubber					
Per unit	6,750	$1600[4]	98.5%	129.7 ppm	wastewater
Total	27,000	$6400			

[1] Includes installation.

[2] Fuel, utilities and maintenance.

[3] Wastes generated by operating pollution control unit.

[4] With recirculation.

TABLE 67. COST OF CONTROL ALTERNATIVES FOR STACK GAS FROM COAL DRYING (82,86)

Basis: 377 m^3/sec at 60°C with a grain loading of 0.65 mg/m^3 (712 ppm)

Treatment	Costs Capital ($1000)	Operating	Efficiency	Emission After Treatment	Secondary Waste
Baghouse filter	1000	NA	99.9%	0.7 ppm	dust
Wet scrubber	380	$ 28,000	98.5%	10.7 ppm	wastewater

and meterological conditions (87). Also, the amount of the duct work required will depend on the flare system distance from the processing units. These factors will affect the cost of the flare system. Steam, if not available from the process plant, will add to the operating cost.

Elevated flare system costs vary considerably because of the disproportionate costs for auxiliary and control equipment and the relatively low cost of the flare stack and burner. As a result, equipment costs are rarely diameter-dependent Typical installed costs for elevated flares range from $30,000-$100,000. Operating costs are determined chiefly by fuel costs for purge gas and pilot burners, and by steam required for smokeless flaring. On the basis of 30 cents per million Btu's fuel requirement, typical elevated stack operating costs are about $1,500 per year (88).

The cost of an elevated flare system for a 7,950 m^3/day SRC plant has been roughly estimated from the cost of a flare system for a 55,650 m^3/day refinery. The 55,650 m^3/day refining flare system incorporates two elevated flares, each costing $100,000, and one ground flare, costing $200,000. The waste gas collection system was valued at $250,000. Total capital cost for the refinery was $750,000 (88).

Using six-tenth factor analysis and assuming a similar scaled down version of the refinery flare system, the cost of a flare system for the SRC plant has been approximated. Results are listed in Table 68.

TABLE 68. ESTIMATED COSTS FOR FLARE SYSTEM OF A 7,950 M^3/DAY SRC PLANT (88)

Unit	Capital Cost	Operating Cost
Elevated flares (2)	$ 64,100	$ 3,000/yr
Ground flare (1)	64,100	1,500/yr
Waste gas collection System	80,000	---
Total	$208,200	$ 4,500/yr

A number of alternatives for controlling sulfur dioxide and particulates in boiler stack gas from steam and power generation have been evaluated. Costs and removal efficiencies for six alternative sulfur dioxide wet scrubbers are compared in Table 69. Additional cost, regulatory, and site specific evaluations are required to select the best alternative for a specified application.

Alternatives for treatment of the low sulfur effluent tail gas discharged from the Stretford sulfur recovery process include direct flame incineration and carbon adsorption with incineration. Table 70 presents cost data, removal efficiencies, emissions characteristics and secondary wastes for these alternatives. From a cost standpoint, carbon adsorption is the preferred alternative, however the after treatment emissions levels are not in compliance with possibly applicable regulatory requirements, for example hydrocarbon emissions in the state of Illinois (see Section 5.0). Regulatory requirements may in some instances require application of secondary sulfur recovery processes such as Beavon and SCOT. The costs of secondary recovery are roughly equal to the costs of primary sulfur recovery (89).

TABLE 69. COSTS, EFFICIENCIES AND FINAL EMISSIONS FOR COMMERCIALLY AVAILABLE SO_2 WET SCRUBBING PROCESSES (90)

Basis: Coal-fired boiler flue gas, 103.6 m^3/sec (2465 ppm SO_2, 6,946 ppm NO_x, and 245.0 gm/m^3 fly ash)

	Costs		Removal Efficiencies			Emissions after Treatment		
Process	Capital ($million)	Operating (Annual) ($ Million)	SO_2	Particulates	NO_x	SO_2	Particulates	NO_x
Lime slurry scrubbing	20.56	12.01	90%	99+%	*	6.97 TPD	0.70 + TPD	*
Soda-limestone double-aklali	26.81	13.21	*	up to 99%	*	*	0.70 TPD	*
MgO scrubbing (recovery)	29.04	13.14	90%	99.5%	*	6.97 TPD	0.35 TPD	*
Limestone scrubbing	24.65	12.16	70-80%	99%	*	17.42 TPD	0.70 TPD	*
Potassium sulfite-bisulfite scrubbing	27.53	11.89	90%	*	*	6.97 TPD	*	*
Wet activated charcoal absorption	*	*	80%	*	*	13.94 TPD	*	*

*Data not available

TABLE 70. TREATMENT ALTERNATIVES FOR STRETFORD TAIL GAS (91,92)

Basis: 82.1 m^3/sec throughput,
hydrocarbon conc. = 5,536 ppm (as ethane)

Treatment	Cost Capital	 Operating	Hydrocarbon Removal Efficiency	Emission After Treatment	Secondary Wastes
	($1000)	(Annual $1000)			
Direct-Flame incineration	572	4,083	98+%	hydrogen sulfide 0.2 ppm sulfur dioxide 17.7 ppm hydrocarbons 79.0 ppm nitrogen oxides 96.6 ppm carbon monoxide 2.5 ppm carbon dioxide 43.6 ppm ammonia 2.0 ppm	Water and carbon dioxide from combustion.
Carbon adsorption with incineration (AdSox)	1,843	3,546	up to 99%	hydrogen sulfide 9.5 ppm sulfur dioxide 278 ppm hydrocarbons 42.9 ppm nitrogen oxides 12.7 ppm carbon monoxide 0.6 ppm carbon dioxide 111 ppm	Water and carbon dioxide from incineration

4.9.2 Water Effluents Control Alternatives

Subsection 4.6.2 suggests application of water effluent controls in SRC systems as follows:

- Use of a tailings pond for water effluents from coal preparation

- Treatment of process wastewaters in one of two wastewater treatment schemes

- Direct discharge of cooling tower blowdown to receiving waters after traditional sidestream treatment.

Economic aspects of coal preparation and other process wastewaters are discussed below.

The relationship between depth and area affects the cost of tailings ponds. Generally cost per unit area increases with depth of the pond, 4.5 meters being the maximum depth recommended for consideration. Table 71 compares costs for two alternative tailings ponds, each of which can meet the needs of a 7,950 m^3/day SRC facility. A polyvinyl chloride (PVC) liner is included in the cost analysis due to the wastewater composition.

TABLE 71. TAILINGS POND (93)

	Costs $1000 Alternative I (4047 m^2, 4.1 m deep)	Alternative II (8094.0 m^2, 2.4 m deep)
Pond	27.0	11.6
Hand Dress Slopes	0.419	0.360
Anchor Ditches	0.298	0.440
Liner (PVC)	5.68	10.350
Liner Installation	0.67	1.22
Contingency	3.4	5.99
Total	37.42	29.97

Costs for the two alternative wastewater treatment plants described in subsection 4.6.2 are given in Table 72. Alternative I appears to be more cost effective.

The two alternate treatment schemes have been extensively used in the petroleum industry for wastewaters containing oils and grease, hydrogen sulfide, ammonia, phenols, and suspended solids. Coal liquefaction publications to date have also indicated that these treatment units are expected to be employed in commercial facilities when built.

4.9.3 Solid Wastes Control Alternatives

The following solid waste discharges, produced by existing industries, also require disposal by operators of SRC systems: water supply sludges, ash from steam and power generation, and coal cleaning refuse. Typical transportation and landfill costs for these solids are approximately $2.72/Mg and $7.72/Mg respectively (6), or a total disposal cost of about $10.44/Mg.

TABLE 72. COSTS OF WASTEWATER TREATMENT PROCESSES FOR SRC SYSTEMS

PROCESSES	COSTS Capital ($1000)	Operating Annual ($1000)
Common Units for Alternatives		
Steam stripping	480.0	81.654
API separatoe	69.0	1.0
Equalization basin		
Aerators and basin	60.0	0.163
Dissolved air flotation		
Flotation unit	90.0	14.0
Chemicals	NA*	NA*
Alternative I		17.4 (Total Cost)
Extended Aeration		
Basin	62.0	----
Air	100.0	----
Clarifier	88.0	----
Chemicals	-----	2.263
Installationq	100.0	----
Filtration Options		
Pressure	87.5	4.083
Gravity	104.5	----
Alternative II		67.12 (Total Cost)
Aerated Lagoon		
Basin	813.0	
Chemicals	-----	2.263
Settler	88.0	----

*NA = not available

In addition, SRC facilities generate the following solid wastes which are unique to liquefaction technology: spent catalysts from hydrotreating and hydrogen production, slag or ash from hydrogen production, wastewater treatment sludges, and any excess mineral residue or filter cake produced. It may be necessary to subject these wastes to additional treatment to condition them for safe final disposal. Alternately, or additionally, disposal sites may require modifications, such as liners and air or water monitoring devices. It is impossible to predict what measures will be required, or their corresponding costs at the time of this writing. Total transportation and landfill costs for all solid wastes produced by the SRC systems are approximately $53 million; however specific requirements for predisposal treatment of wastes or landfill site conditioning would require revision of this estimate.

5.0 ANALYSIS OF REGULATORY REQUIREMENTS AND ENVIRONMENTAL IMPACTS

This section describes the EPA and other methodologies that should be useful in establishing the environmental viability of a commercial SRC liquefaction system. The standards and criteria established for point source pollutants under the amended Clean Air, Clean Water, and Resource Conservation and Recovery Acts, among others, are summarized and compared with the predicted levels of inorganic and organic pollutants in waste streams. Multimedia impacts resulting from the discharge of various waste streams, products, and by-products are estimated in accordance with the evolving protocols specified in the Multimedia Environmental Goals (MEGs), Source Analysis Models (SAMs) and Bioassay protocols currently being developed by the Industrial Environmental Research Laboratory at Research Triangle Park, NC (IERL/RTP).

5.1 Environmental Impact Methodologies

5.1.1 Multimedia Environmental Goals

Multimedia Environmental Goals (MEGs) are defined as levels of significant contaminants or degradents (in ambient air, water, or land, or in emissions or effluents discharged from a source to the ambient media) that are judged to be: (1) appropriate for preventing certain negative effects in the surrounding populations or ecosystems, or (2) representative of pollutant control limits achievable through technology. MEG values are currently projected for more than 650 pollutants. This list, to be expanded and revised as emergent data warrant, was compiled on the basis of descriptions in the literature of fossil fuels processes and of the associated hazardous substances.

Both Ambient Level Goals and Emission Level Goals based on ambient factors are addressed in the MEGs. Existing or proposed federal standards, criteria, or recommendations are acknowledged as previously established goals and have been utilized wherever applicable. For those substances not addressed by current guidelines, empirical data indicating toxic potential, reactions, and associations of the substance within the various media, natural background levels, and the conditions under which the substance may be emitted and dispersed, have been utilized for the purpose of developing MEGs.

The MEG concept represents an important step in EPA's efforts to address systematically the problem of establishing priorities for environmental assessment programs. MEGs provide a ranking system for chemical substances on which to base decisions concerning source assessment. The MEGs may also be used to establish priorities for the pollutants to be addressed by regulations, and thus, may influence future control technology development.

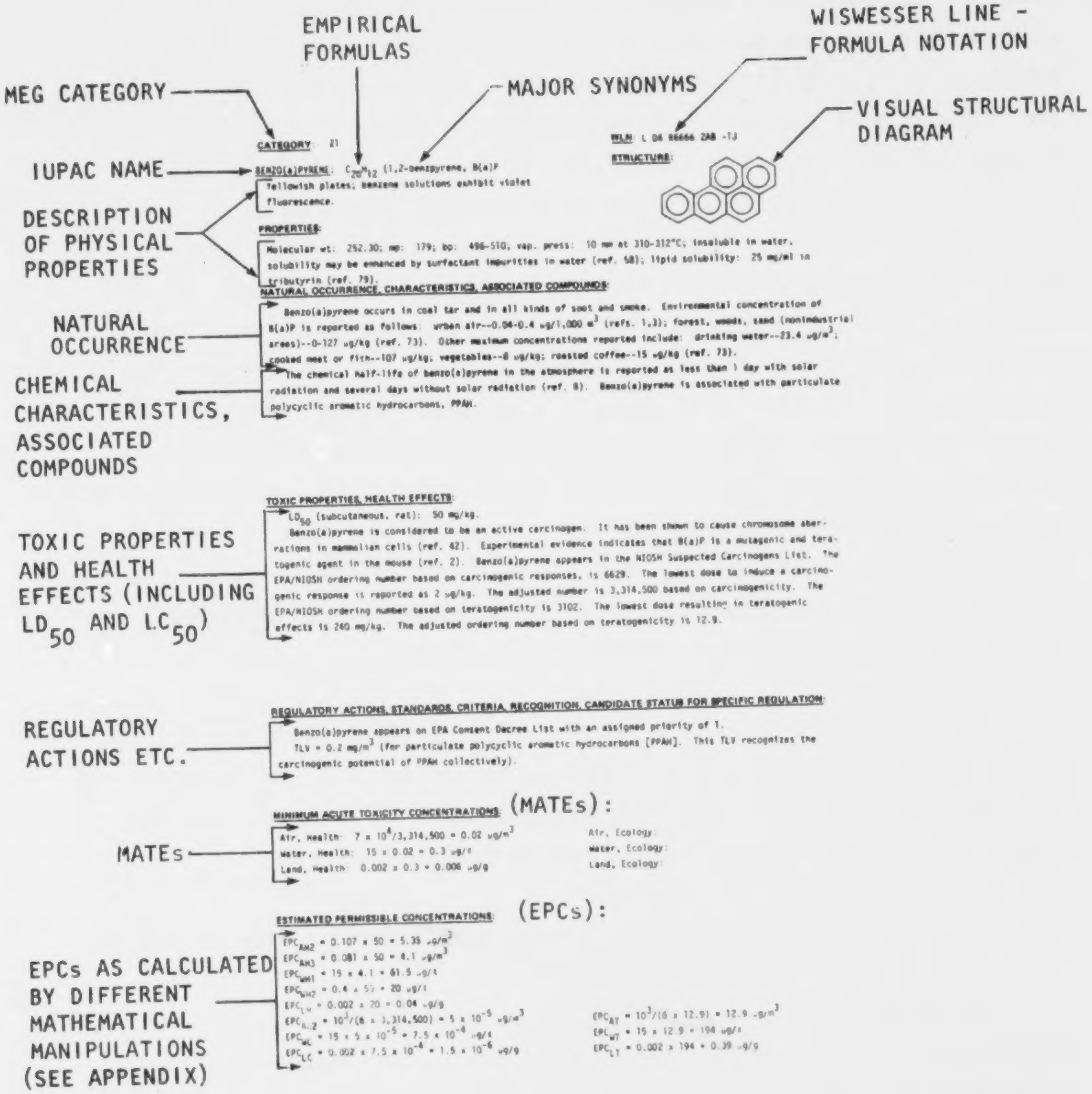
The MEGs can be used by environmental assessors including engineers, chemical analysts, toxicologists, industrial hygienists, system modeling experts, and inspectors or plant monitoring personnel. They can be used alone as a manual or workbook with future supplements to update the data. The MEGs establish a baseline of information for a great number of substances and allow consideration of the potential pollution hazard of these substances. Continued research and reviews are obviously necessary to fill the many information gaps that still exist; these gaps result either because the data are nonexistent or the data are not readily available in the literature. More detailed discussion of these major concerns is given in the Appendix of this report and in an earlier report (43).

The MEG values are based, in part, on the concentrations of pollutants already promulgated in existing or proposed federal standards, criteria or recommendations, and an acceptable empirical data relating to toxicity and health effects in the multimedia context. Although the MEG concept, in its current state of development, contains several simplifying assumptions, the benefits to be realized from its preliminary application seem to outweigh the risks of any oversimplification. Furthermore, the overall MEG concept should provide preliminary decision criteria for all of the emerging coal conversion systems (i.e., gasification and liquefaction) that require methodologies for environmental assessment. At the very least, the MEG concept should generate further comments on possible applications, as well as suggestions for refining the models used to calculate the MEGs. MEGs can be used not only to evaluate the potential hazards of various pollutants in waste streams, but also to assess the need for making necessary changes in design, inspection, and/or maintenance protocols.

The format for presentation of the MEGs consists of two forms used together. The first form is called the Background Information Summary, and the second form is called the MEG chart; these two forms are discussed subsequently.

5.1.1.1 Background Information Summaries for the MEGs

An example of a MEG Background Information Summary (for benzo(a)pyrene) is shown in Figure 56. The MEG Background Information Summary gives the International Union of Pure and Applied Chemistry's (IUPAC) name of the material, the empirical chemical formula, major synonyms, a description of the physical properties, the Wiswesser Line-Formula notation,


EMPIRICAL FORMULAS
WISWESSER LINE - FORMULA NOTATION
MEG CATEGORY
MAJOR SYNONYMS
VISUAL STRUCTURAL DIAGRAM
IUPAC NAME
DESCRIPTION OF PHYSICAL PROPERTIES
NATURAL OCCURRENCE
CHEMICAL CHARACTERISTICS, ASSOCIATED COMPOUNDS
TOXIC PROPERTIES AND HEALTH EFFECTS (INCLUDING LD50 AND LC50)
REGULATORY ACTIONS ETC.
MATEs
EPCs AS CALCULATED BY DIFFERENT MATHEMATICAL MANIPULATIONS (SEE APPENDIX)

CATEGORY: 21

WLN: L D6 B6666 2AB -TJ

BENZO(a)PYRENE: $C_{20}H_{12}$ (1,2-benzpyrene, B(a)P

Yellowish plates; benzene solutions exhibit violet fluorescence.

STRUCTURE:

PROPERTIES:

Molecular wt: 252.30; mp: 179; bp: 496-510, vap. press: 10 mm at 310-312°C; insoluble in water, solubility may be enhanced by surfactant impurities in water (ref. 58); lipid solubility: 25 mg/ml in tributyrin (ref. 79).

NATURAL OCCURRENCE, CHARACTERISTICS, ASSOCIATED COMPOUNDS:

Benzo(a)pyrene occurs in coal tar and in all kinds of soot and smoke. Environmental concentration of B(a)P is reported as follows: urban air--0.04-0.4 μg/1,000 m^3 (refs. 1,3); forest, woods, sand (nonindustrial areas)--0-127 μg/kg (ref. 73). Other maximum concentrations reported include: drinking water--23.4 μg/m^3; cooked meat or fish--107 μg/kg; vegetables--8 μg/kg; roasted coffee--15 μg/kg (ref. 73).

The chemical half-life of benzo(a)pyrene in the atmosphere is reported as less than 1 day with solar radiation and several days without solar radiation (ref. 8). Benzo(a)pyrene is associated with particulate polycyclic aromatic hydrocarbons, PPAH.

TOXIC PROPERTIES, HEALTH EFFECTS:

LD_{50} (subcutaneous, rat): 50 mg/kg.

Benzo(a)pyrene is considered to be an active carcinogen. It has been shown to cause chromosome aberrations in mammalian cells (ref. 42). Experimental evidence indicates that B(a)P is a mutagenic and teratogenic agent in the mouse (ref. 2). Benzo(a)pyrene appears in the NIOSH Suspected Carcinogens List. The EPA/NIOSH ordering number based on carcinogenic responses, is 6629. The lowest dose to induce a carcinogenic response is reported as 2 μg/kg. The adjusted number is 3,314,500 based on carcinogenicity. The EPA/NIOSH ordering number based on teratogenicity is 3102. The lowest dose resulting in teratogenic effects is 240 mg/kg. The adjusted ordering number based on teratogenicity is 12.9.

REGULATORY ACTIONS, STANDARDS, CRITERIA, RECOGNITION, CANDIDATE STATUS FOR SPECIFIC REGULATION:

Benzo(a)pyrene appears on EPA Consent Decree List with an assigned priority of 1.

TLV = 0.2 mg/m^3 (for particulate polycyclic aromatic hydrocarbons [PPAH]. This TLV recognizes the carcinogenic potential of PPAH collectively).

MINIMUM ACUTE TOXICITY CONCENTRATIONS (MATEs):

Air, Health: $7 \times 10^4/3,314,500 = 0.02$ μg/m^3	Air, Ecology:
Water, Health: $15 \times 0.02 = 0.3$ μg/ℓ	Water, Ecology:
Land, Health: $0.002 \times 0.3 = 0.006$ μg/g	Land, Ecology:

ESTIMATED PERMISSIBLE CONCENTRATIONS (EPCs):

$EPC_{AH2} = 0.107 \times 50 = 5.35$ μg/m^3

$EPC_{AH3} = 0.081 \times 50 = 4.1$ μg/m^3

$EPC_{WH1} = 15 \times 4.1 = 61.5$ μg/ℓ

$EPC_{WH2} = 0.4 \times 50 = 20$ μg/ℓ

$EPC_{LH} = 0.002 \times 20 = 0.04$ μg/g

$EPC_{AC2} = 10^3/(6 \times 3,314,500) = 5 \times 10^{-5}$ μg/m^3

$EPC_{WC} = 15 \times 5 \times 10^{-5} = 7.5 \times 10^{-4}$ μg/ℓ

$EPC_{LC} = 0.002 \times 7.5 \times 10^{-4} = 1.5 \times 10^{-6}$ μg/g

$EPC_{AT} = 10^3/(6 \times 12.9) = 12.9$ μg/m^3

$EPC_{WT} = 15 \times 12.9 = 194$ μg/ℓ

$EPC_{LT} = 0.002 \times 194 = 0.39$ μg/g

Figure 56. Background information sample summary for benzo(a)pyrene (39)

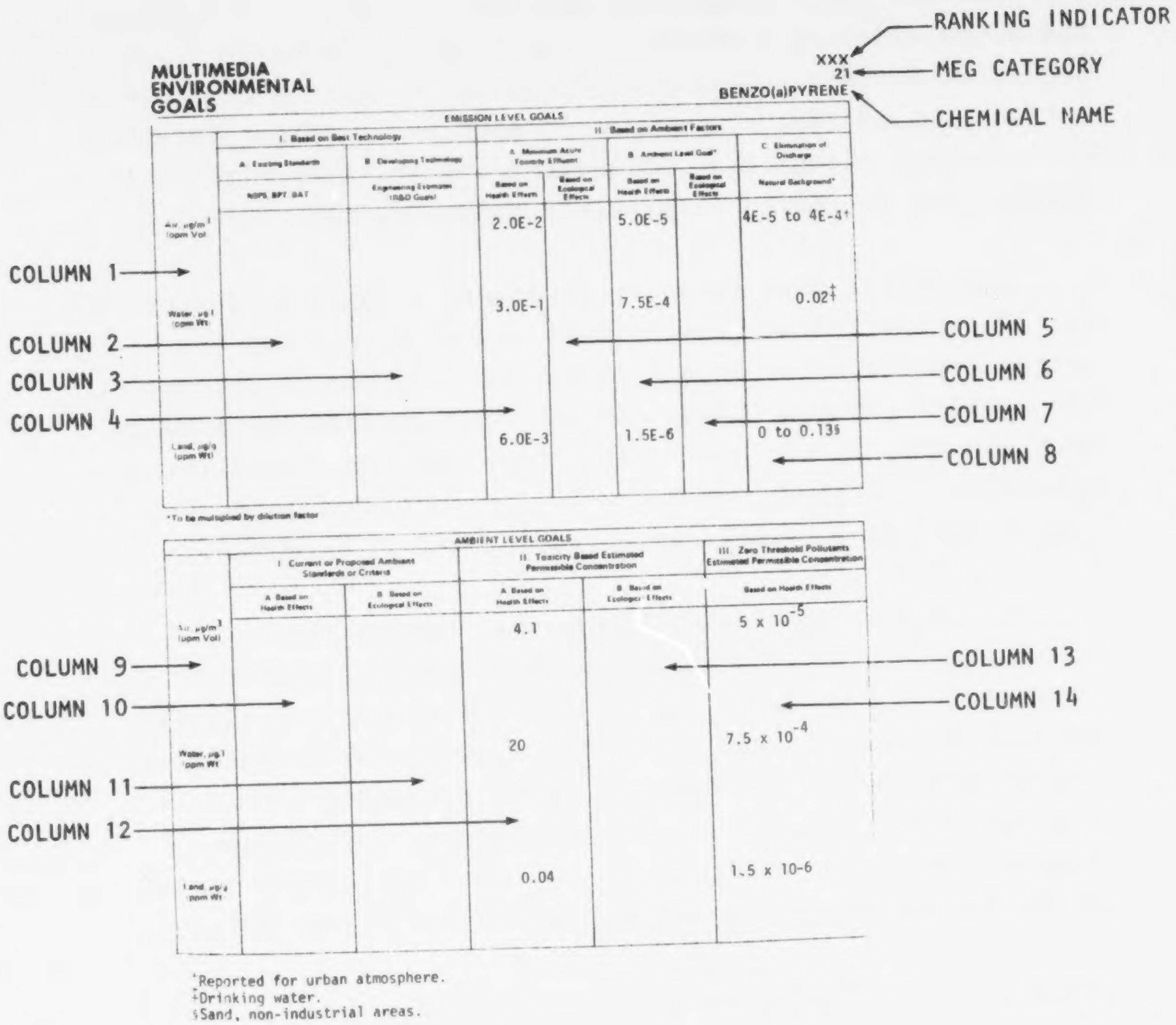
and a visual structural diagram. The Wiswesser Line-Formula notation gives a unique unambiguous topological description of the structure of each substance. The natural occurrence, characteristics, and associated compounds are also catalogued. The reported toxic properties and health effects including the NIOSH ordering numbers for carcinogens are given. The potential for bioaccumulation is given as well as regulatory actions, standards, criteria, recognition, candidate status for specific recognition, Minimum Acute Toxicity Effluents (MATEs) and Estimated Permissible Concentrations (EPCs).

The lethal dose (usually given all at once by injection) for 50 percent of all the animals tested (LD_{50}) and the lethal concentration in air, water or food for 50 percent of the animals exposed (LC_{50}) are also included in the summary. When the LD_{50} is not available, the lowest published lethal dose (LD_{Lo}) is given, when the LC_{50} is not available, the lowest published lethal concentration (LC_{Lo}) is given.

At the bottom of each Background Summary sheet, the actual calculations for both the MATE values and EPCs of the substances are given to indicate the derivation of figures entered in the MEG charts. Only the equations defining the lowest MATE values in each medium are presented. By displaying these calculations, the Background Information Summary offers the opportunity to relate the values listed on the MEG charts to the data from which they are derived.

5.1.1.2 Discussion of the MEG Chart

Figure 57 is an example of a MEG chart. Emission Level Goals, which are listed in the top half of the figure (Columns 2-8) are acceptable levels of contaminants in point source or fugitive emissions. Discharge streams included in


RANKING INDICATOR
MEG CATEGORY
CHEMICAL NAME
COLUMN 1
COLUMN 2
COLUMN 3
COLUMN 4
COLUMN 5
COLUMN 6
COLUMN 7
COLUMN 8
COLUMN 9
COLUMN 10
COLUMN 11
COLUMN 12
COLUMN 13
COLUMN 14

MULTIMEDIA ENVIRONMENTAL GOALS

XXX
21
BENZO(a)PYRENE

EMISSION LEVEL GOALS

	I. Based on Best Technology		II. Based on Ambient Factors				
	A. Existing Standards	B. Developing Technology	A. Minimum Acute Toxicity Effluent		B. Ambient Level Goal*		C. Elimination of Discharge
	NSPS, BPT, BAT	Engineering Estimates (R&D Goals)	Based on Health Effects	Based on Ecological Effects	Based on Health Effects	Based on Ecological Effects	Natural Background*
Air, µg/m³ (ppm Vol)			2.0E-2		5.0E-5		4E-5 to 4E-4†
Water, µg/l (ppm Wt)			3.0E-1		7.5E-4		0.02‡
Land, µg/g (ppm Wt)			6.0E-3		1.5E-6		0 to 0.13§

*To be multiplied by dilution factor

AMBIENT LEVEL GOALS

	I. Current or Proposed Ambient Standards or Criteria		II. Toxicity Based Estimated Permissible Concentration		III. Zero Threshold Pollutants Estimated Permissible Concentration
	A. Based on Health Effects	B. Based on Ecological Effects	A. Based on Health Effects	B. Based on Ecological Effects	Based on Health Effects
Air, µg/m³ (ppm Vol)			4.1		5×10^{-5}
Water, µg/l (ppm Wt)			20		7.5×10^{-4}
Land, µg/g (ppm Wt)			0.04		1.5 x 10-6

†Reported for urban atmosphere.
‡Drinking water.
§Sand, non-industrial areas.

Figure 57. Sample MEG chart (39)

Emission Level Goals may be gaseous, aqueous, or solid in nature (as listed in Column 1). Emission Level Goals for chemical contaminants may be described on the basis of technology factors or ambient factors. Technology-based Emission Level Goals (Section I, top left half of the figure, Columns 2 and 3) have not been addressed in the current MEGs.

Five specific criteria for Emission Level Goals based on ambient factors (Columns 4-8) have been included in the MEG methodology. These are: Minimum Acute Toxicity Effluents (MATEs) Column 4 based on human health effects; MATEs based on ecological effects (Column 5); Ambient Level Goals (Column 6) based on human health effects; Ambient Level Goals based on ecological effects (Column 7); and concentrations representing Elimination of Discharge (EOD, Column 8).

MATEs are concentrations derived from calculations of laboratory-determined values or federal regulations which are hoped not to cause environmental damage if present in the waste streams which are allowed to interact with the environment (Column 5) and which will not cause health problems for the employees of the facility (Column 4). The Ambient Level Goals (Columns 6 and 7) are simply transcriptions of the lowest Current or Proposed Ambient Standards or Criteria (Columns 10 and 11), or Estimated Permissible Concentrations (EPCs) (Columns 12 and 13 in the lower half of the figure). Both MATEs and all ambient level goals are derived from literature values and are based on health and ecological effects.

Emission Level Goals derived from Ambient Level Goals are usually more stringent than MATEs. These values, multiplied by dilution factors, then describe control levels for emissions that will not cause contaminant concentrations in ambient media to exceed the suggested Ambient Level Goals.

Dilution factors are dimensionless quantities representing the ratio of the concentration of a contaminant in an emission or effluent to the resulting contaminant level in the ambient receiving medium. As an example, consider an emission from a stack discharged to the atmosphere. The dilution factor is the concentration of a pollutant in the stack gas divided by the resulting ground level concentration of the pollutant. Since the dilution factors are variable and highly source specific, no effort has been made to provide the Emission Level Goals with dilution factors applied. Instead, the multiplication exercise is left to the individual applying the charts to a specific industrial situation.

Although dilution factors do not appear on the MEG charts, consideration has been given to the range of factors likely to be encountered in most situations. Dilution factors may be expected to range between 10 and 10,000 for discharges to air and water. This range is suggested on the basis of the best and worst case models of pollutant dispersion.

Emission Level Goals based on Elimination of Discharge (Column 8), like those based on Ambient Level Goals incorporate dilution factors. These goals are the most stringent and imply that ambient concentrations of pollutants should not exceed natural background concentrations.

Values appearing on the MEG chart under Emission Level Goals, based on EOD, indicate natural background levels (Column 8). Concentrations measured in rural atmosphere are entered for air. When rural atmosphere concentrations are not reported, urban or industrial concentrations may be entered on the chart with a footnote to characterize the value. Concentrations entered in the MEG chart for water are for surface waters unless otherwise specified. Levels identified in drinking water and in seawater are included since they provide some information of natural background concentrations.

MATE and Ambient Level Goals (Columns 4-7) are intended to serve as indicators of relative hazard and as estimates of contaminant levels in waste streams that will prevent serious acute toxic effects. These indicators should be useful to those involved in environmental assessment by furnishing emission level goals, potential environmental hazard levels, and ultimately control technology goals. Since MATEs are derived from estimations of hazards to human health or to ecology induced by short-term exposure to pollutants in waste streams (less than 8 hours per day), they can serve as an estimate of levels of contaminant considered to be safe for short term exposures. The MATE values should provide an increasingly useful tool for comparisons in environmental assessment.

The methodology for estimating Emission Level Goals was designed to make use of (1) the concentrations described as Ambient Level Goals based on hazards posed to public health and welfare as a result of long term or continuous exposure to emissions, (2) natural background levels which provide goals for elimination of discharge, and (3) hazards to human health or to ecology induced by short term exposure to emissions. The need is clear for further research and development of simple but effective models incorporating data pertinent to the following: quality of the receiving media before introduction of the substance, characteristics of transport and dispersion of emissions, considerations of location and abundance of sources emitting a given pollutant, number of populations affected, and secondary pollutant formations.

Ambient Level Goals (Columns 10-14) are concentrations of the pollutants listed in Column 9 which should not cause the level of contamination in ambient media to exceed a safe continuous exposure concentration. They are derived from three distinct data sources: (1) the most stringent current or proposed federal ambient standards or criteria (Columns 10 and 11), (2) empirical data concerning the adverse effects of chemical substances on human health and ecology (Columns 12 and 13), and (3) a system relating the carcinogenic or teratogenic potential of specific chemical substances to media concentrations considered to pose an acceptable risk upon continuous exposure (Column 14).

A system has been developed for assigning indicators (X, XX, or XXX) to designate potentially hazardous substances based on values generated by the MEG methodology (see upper right hand corner of Figure 57). This system provides a simple means of identifying through cursory inspection those pollutants most likely to pose a human threat. The substances which have currently been addressed by the MEG methodology have been ranked accordingly and classified as relatively nonhazardous (no indicator), hazardous (X), very hazardous (XX), or most hazardous (XXX). All substances which have been ranked are found in Table 72. This table can be used to compare the relative hazard of two or more pollutants. However, once specific discharge data are obtained, the discharge is evaluated based on the pollutants' concentrations and hazard rating is superceded.

TABLE 73. RANKING OF THE MATERIALS ADDRESSED BY THE CURRENT MEG'S ACCORDING TO POTENTIAL ENVIRONMENTAL HAZARD

MOST HAZARDOUS (XXX)

3-Methylcholanthrene
Beryllium
Chromium
Cadmium
Mercury
Dibenz(a,h)anthracene
N-Nitrosodimethylamine
Nickel
7,12-Dimethylbenz(a)anthracene
Benzo(a)pyrene
Antimony trioxide
Selenium
Arsenic
Arsine
Arsenic trioxide

VERY HAZARDOUS (XX)

Benz(a)anthracene
Dibenzo(a,i)pyrene
Cobalt
Nickel carbonyl
N,N'-Dimethylhydrazine
Diazomethane
Lead
Polychlorinated biphenyls
4,6-Dinitro-o-cresol
2,4,6-Trinitrophenol
Tetramethyllead
Alkyl mercury
Organotin
Thallium
Phosphorous
Phosphine
Antimony
Bismuth
Hydrogen selenide
Copper
Uranium
Ethyleneimine
N-Nitrosodiethylamine
Hydrazine

HAZARDOUS (X)

Monomethylhydrazine
Dibenz(a,j)acridine
Dibenz(a,h)acridine
Dibenzo(c,g)carbazole
Tetraethyllead
Aminotoluenes
1-Aminonaphthalene
2-Aminonaphthalene
Acrolein
Lithium
Lithium hydride
Barium
Germanium
Tellurium
Vanadium
Formaldehyde
Nickelocene
2,4-Dichlorophenol
N,N-Dimethylhydrazine
1,2-Diphenylhydrazine
Nitrobenzene
1-Chloro-2-nitrobenzene
Dinitrotoluenes
Xylenols
3-Nitrophenol
4-Nitrophenol
Dinitrophenols
Pyridine
Gallium
Hydrogen cyanide
Manganese
Copper-8-hydroxyquinoline
Silver
4-Aminobiphenyl
Benzene
4-Nitrobiphenyl

(continued)

TABLE 73. (continued)

RELATIVELY NONHAZARDOUS (NO INDICATOR)

1-Phenyl ethanol
Ethylene glycol
Formic acid
Phthalic acid
Tetramethylsuccinonitrile
Ethanolamine
Butylamines
p-Dimethylaminoazobenzene
Methanethiol
Ethanethiol
n-Butanethiol
Biphenyl
Phenathrene
Chrysene
Methylchrysenes
Benzo(e)pyrene
Picene
Dibenzo(a,h)pyrene
Dibenzo(a,l)pyrene
Benzo(j)fluoranthene
Benzo(b)fluoranthene
Ideno(1,2,3-cd)pyrene
Phenyl phenols
Isophorone
Formamide
Aniline
Phenol
Cresols
Alkyl cresols
Catechol
2-Chlorophenol
2-Nitrophenol
1-Chloro-2,3-epoxy propane
Naphthalene
2,2'-Dichloroethyl ether
Tertiary pentanol
Propionaldehyde
Acetic acid
Hydroxyacetic acid
Acetonitrile
Acrylonitrile
Benzonitrile
Cyclohexylamine
Dimethylamine
Quinoline, isoquinoline
Pyrrole
Dibenzo(a,g)carbazole
Thiophene
Methyl thiophenes
Potassium
Magnesium
Magnesium oxide
Strontium
Boron
Boron oxide
Aluminum
Aluminum oxide
Alkali cyanide
Hydrogen sulfide
Titanium
Molybdenum
Tungsten
Zinc
Benzidine
-Chlorotoluene
Vinyl chloride
Benzo(c)phenanthrene
Pyrene
Benzo(c)phenanthrene
Dibenz(a,c)anthracene
Benz(c)acridine
Dibenz(c,h)acridine
Dibenzo(a,i)carbazole
Methanol
Ethanol
1,4-Dichlorobenzene
Indanols
Tetrahydrofuran
Methane
Ethane
Propane
Butanes
Ethylene
Propylene
Acetylene
Methyl chloride
Methalene chloride
1,4-Dioxane

(continued)

TABLE 73. (continued)

RELATIVELY NONHAZARDOUS (NO INDICATOR) CONTINUED

Dimethylaniline
N,N-Dimethylaniline
Benzenesulfonic acid
Idene
Nitrotoluenes
Fluoranthene
Picolines
Collidines
Methylquinolines
Methylisoquinolines
Acridine
Indole
Carbazole
Benzo(b)thiophene
Ferrocene
Carbon monoxide
Ammonia
Ozone
Carbon disulfide
Scandium
Anthracene
n-Butanols
Isobutyl alcohol
Pentanols (primary)
2-Propanol
2-Butanol
Pentanols (secondary)
Tert-butanol
Acetaldehyde
Butyraldehyde
Benzoic acid
Toluene
Ethyl benzene
Indan
Xylenes
Tetrahydronaphthalene
Chlorobenzene
1,2-Dichlorobenzene
2-Chlorotoluene
Carbon dioxide
Carbonyl sulfide

The following compounds have not been assigned hazard potential values:

Naphthacene
Triphenylene
Dimethyl pyrenes
Perylene
Benzo(g,h,i)perylene
Coronene
Fluorene
2,3-Benz-4-azafluorene
Phosphate

5.1.1.3 MEGs for Nonchemical Pollutants

Cornaby and coworkers (94) reported that nonchemical pollution factors such as heat, noise, microorganisms, and land usage can be adapted to the MEG approach. They reported that complex effluents (i.e., entire waste streams) should be amenable to the MEG approach as well. Other factors such as radionuclides, electromagnetic radiation and water usage may also be compatible with the MEG approach.

With regard to the heat effect, Cornaby and coworkers suggested that the ambient air MEG be a wet bulb globe temperature of 30°C. The MEG for water should be 2.8C° above the natural or ambient temperature for the body of water. The ambient air-temperature MEG should be based on physiological factors to assure human survival, assuming continuous light work and proper precautions to avoid the effects of water and salt depletion. The temperature MEG for water is thought to be sufficient to protect most aquatic populations from the many biological effects associated with elemental waste temperatures.

Noise values were judged to be adaptable to the MEG format. A level of 60 dB(A) was recommended as a reasonable environmental objective. This is the approximate noise emitted by an air conditioner 6 meters away. The noise of freeway traffic at 15 meters (70 dB(A)) makes telephone use difficult and can contribute to hearing impairment. Adverse effects due to noise include physiological stress reaction, sleep disturbance, and simple annoyance. The suggested standard is dropped to 45 dB(A) for noise between the hours of 10 p.m. and 7 a.m. since significant proportions of the populations experience sleep disturbances, difficulty in communication, and subjective annoyance in the range of 45-

65 dB(A). Studies have indicated that animals other than humans would not be disturbed by this noise level.

Land usage can be adapted to the MEG format (43). There are many ways of measuring land usage, such as density of human and nonhuman organisms, and a MEG chart should be developed for each. The rationale for use of the density of animals to determine which land tract should be developed is that the lower the density, the fewer people and organisms would be impacted. The wildlife density is related to the quality of the habitat.

5.1.1.4 MEGs for Entire Emission Streams

Complex effluents such as entire emission streams should be amenable to the MEG approach. However, the lack of information on the ecotoxicological effects of complex effluents prevents such calculations.

Some significant mortality/morbidity studies have been performed and are summarized in Table 74. This type of information lends itself to the development of MEGs for

TABLE 74. EPIDEMIOLOGICAL MORTALITY/MORBIDITY STUDIES[a]

Response	Pollution Specifics	Human Sub-Population Exposed	 Non-Exposed
Infant Mortality	Daulphin Co., PA., U.S.A. General Air Pollution	1. Infants born during high air pollution months (July, August, September) represented 50%(+) of the total annual infant mortality or 18% of infant deaths/month. (66 cases)	1. The study demonstrated thru matched pairs that those born during non-pollution alerts had lower mortality. (~5% of infant deaths/month)
Infant Mortality	Nashville, TN, U.S.A. City Air: Means ($\bar{X}$) 22.4 $mg/m^2/ton$ - Sulfation 2.559 $gm/m^2/month$ - Dustfall 1.65 COHS/km - Soiling 0.0075 24 hr ppm - 24 hr SO_2 Country air not reported (assumed to be less).	1. White neonatal mortality ratio (1960) of 18.2/1,000 live births.	1. White neonatal mortality ratio for neighboring rural county: 14.0/1,000 (U.S.A. avg. is 10.3/1,000).
Adult Mortality	Coal fired electric power plant in PA, U.S.A. 151 $\mu g/m^3$ suspended particulate 3.70 $mg/m^2/day$ sulfation rate	Town of Seward, PA. 1. Sex & age adjusted death rate of Seward exceeded that of New Florence for 10 out of 11 years. ($\leq .05$)	Town of New Florence, PA. (see exposed)
	Exposed was 9 x SO_2 6.2 x sulfation rate, 3.2 x dust fall, and 1.4 x suspended particles that of unexposed.	2. Three times as many expected cirrhosis deaths.	
Morbidity (chronic destructive pulmonary disease)	Ontario, Canada Nickel & Copper Smelter Exposed 32.5 ppb - SO_2 52.1 $\mu g/m^3$ - Suspended particulate Non-Exposed 16.1 ppb - SO_2 90.5 $\mu g/m^3$ - Suspended particulate	Town of Sudbury: 1. Male prevalence rate of 112/1,000 for chronic bronchitis. 2. Total male & female prevalence rate of 97/1,000. 2208 people studied.	Town of Ottawa: 1. Male prevalence rate of 81/1,000 for chronic bronchitis. Total male & female prevalence rate of 77/1,000. 3280 people studied.
Morbidity (pulmonary function testing)	Ohio, U.S.A. Urban - Industrial (exposed) 10.1 $g/m^3/day$ - SO_3 40.98 $g/m^2/month$ - dust fall 109.27 $\mu g/m^3/24$ hr - total suspended particles) Rural (Non-Exposed) 7.6 - SO_3 2.10 - dust fall 83.30 - total suspended particles	1. The vital capacity (VC) & Forced Expiratory Volume (FEV) 0.75 are significantly lower than for students in rural areas (173 people studied).	1. Higher VC & FEV's than urban population. (161 people studied)

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[a] Cornaby, B.W., D.A. Savitz, M.E. Stout, G.E. Pierce, and A.W. Rudolph. Development of Goals for Nonchemical and Nonpollutant Factors in Fluidized-Bed Combustion -- Draft Report. Technical Directive 31, Contract No. 68-02-2138, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, 1977.

impacts on human health; however, more statistical analyses of such studies are needed in order to define a specific MEG. Mortality studies are currently being performed on the entire coal cycle by the Brookhaven and the Argonne National Laboratories of the U.S. Department of Energy.

MATE values for specific chemical contaminants, although valuable, are not sufficient to characterize an environmentally acceptable waste stream. Ceiling values for certain "Totals" associated with gaseous, aqueous, or solid wastes are also required. Such totals are to be used in conjunction with the MATEs for specific chemical contaminants and provide a secondary check for contaminant levels.

Selection criteria for "Totals" are:

- The parameter must be related to the presence of more than one chemical substance.
- The parameter must be federally regulated in some context. Federal guidelines surveyed for possible totals to be addressed include NAAQS, NSPS, effluent guidelines, drinking water standards, and water quality criteria.
- The parameter must be measurable by some established method.

The following parameters are classified as "Totals" to be addressed by MATEs:

Air	Water	Land
Total hydrocarbons	Total suspended solids	Total leachable organics
Total particulates	Total dissolved solids	Total leachable substances
	Total organic carbon (TOC)	
	Biological oxygen demand (BOD)	
	Chemical oxygen demand (COD)	

Ultimately, a MATE value will be specified for each "Total" listed. MATE values for the land totals may be based on water MATE totals via a leaching model.

Algorithms designed to generate EPCs and MATEs for specific chemical contaminants are not applicable to Totals. Instead, attention must be given to each parameter in order to recommend a MATE value.

Values for Totals will be recommended later with consideration given to: existing regulations and recommendations; associated toxicity; dilution factors expected at the site of dispersion of the effluent; and the nature of the environmental problems associated with the substances indicated by the Totals.

5.1.1.5 Derivation of the MEGs

MATE and EPC values that serve as Emission Level and Ambient Level Goals are derived by multiplication factors which translate empirical data for each specific chemical substance into concentrations describing minimum acute toxicity concentrations. The rationale behind the derivation of a numerical value for each of the factors is described in the Appendices of this report. For each chemical substance addressed, there can be a maximum of six MATE and 15 EPC values. The types of empirical data used to derive MATE and EPC values are as follows:

LD_{50} -- dosage resulting in death (lethal dose) for 50 percent of the animal population tested

LD_{Lo} -- lowest lethal dose reported for a species/route combination

LC_{50} -- lethal concentration to 50 percent of the animals tested

TD_{Lo} -- lowest dosage reported to result in a specified response (for example, a carcinogenic response)

TL_m -- threshold limit median, i.e., concentration to which 50 percent of aquatic population exposed exhibited the specified response

TLV -- threshold limit value, refers to permissible levels of toxic substances for occupational exposure

LC_{Lo} -- lowest lethal concentration reported

TC_{Lo} -- lowest toxic concentration reported to result in a specified response

In derivation of the MEGs, the preferred LD_{50} is for oral administration of the compound to a rat. When this parameter has not been measured, the most closely related LD_{50} or LD_{Lo} is used; a subjective decision as to which is the most closely related LD_{50} or LD_{Lo} is required.

The use of mathematical formulae for translating animal toxicity data into EPCs or MATEs requires that certain assumptions be made. A worst-case approach has been taken to keep the MEG values conservative. Generally, MEGs derived from models which use LD_{50} or other acute toxicity animal data are more conservative than MEGs based on TLVs or NIOSH recommendations. In addition to the assumptions required for extrapolating animal data to human health effects, arbitrary constants are usually employed as safety factors.

5.1.1.6 Derivation of Zero Threshold EPCs

Zero threshold pollutant EPCs (Column 14 of Figure 57) are derived from an earlier model which translates adjusted ordering numbers into permissible concentrations for air or water media. Zero threshold pollutants refer to mutagens carcinogens, and teratogens (collectively called genotoxins) for which there may be no concentration in air or water having a zero effect on nontarget organisms, including man. An acceptable level for one of these genotoxins is usually considered to be one such that the chance of a specific hit is so low that the incidence of carcinogenesis, teratogenesis, or mutagenesis will not be significantly increased (at the 95 percent level) over the situation in which the compound is not present. In other words, at the 95 percent level of statistical significance, the rate of carcinogenesis, mutagenesis or teratogenesis would quite probably be less than or equal to 1.05 times the rate when no genotoxin is present.

The chance of a "single hit" at a specific site by any one particular chemical depends on the availability of the site to that chemical, and the reactivity of that chemical at the site. The factors influencing the availability of the site to the chemical range from sterochemical considerations of the site and the chemical, to the route and efficiency of absorption of the chemical into the organism. In turn, the routes and efficiencies of absorption of chemicals are dependent on the form and availability of the chemical to the organism, and the general health and nutritional status of the organism. Thus, the potency of chemical genotoxins differs greatly, and the acute toxic parameters discussed previously give no indication of the carcinogenic, mutagenic, or teratogenic effects of a compound. Thus, the EPCs for genotoxins have been derived from a model which translates adjusted ordering numbers, based on a ranking system for suspected carcinogens, into permissible media concentrations. The system for establishing adjusted ordering numbers is a refinement of an ordering plan developed by the EPA Office of Toxic Substances, and reported in An Ordering of the NIOSH Suspected Carcinogens List Based on Data Contained in the List (95). EPA's ordering plan resulted in the assignment of four digit ordering numbers (hereafter referred to as EPA/NIOSH ordering numbers) for all those substances entered in the NIOSH Suspected Carcinogens List. The numbers assigned to the EPA plan are an "indication of the relative degree of concern that might be warranted for a particular substance regarding its possible carcinogenic potential (95)." It is not appropriate, however, to conclude that all the substances assigned an adjusted number are carcinogenic.

The following equation describes the modified or adjusted ordering numbers:

$$\text{Adjusted ordering number} = \frac{\text{EPA/NIOSH ordering Number}}{\text{Lowest dosage resulting in an oncogenic response (mg/kg)}}$$

Adjusted ordering numbers determined for various substances (see Table 75), usually range from less than 0.1 to greater than 3,000,000. Very large adjusted ordering numbers indicate that a small dosage was required to effect the response. On the other hand, a small number indicates a high dosage was required. Thus, adjusted ordering numbers increase with the expected potency of a chemical carcinogen. Substances with adjusted ordering numbers lower than one are generally not treated as suspected carcinogens in the calculation of the EPCs.

5.1.2 Source Analysis Models (96)

Source Analysis Models (SAMs) allow the quick identification of possible problem areas where the suspected pollutant exceeds the MEG. The SAM format focuses on each separate waste stream which arises during energy production by industrial processes. Such streams may exist because of the process itself, or because of the application of pollution control technology to a process-generated stream.

SAMs address source identification and stream composition questions; MEGs by definition, address goals. Various members of the set of SAMs will provide rapid screening, intermediate, or detailed approaches to relate effluent stream pollutant emission levels to the MEGs. Later members of the sequence of SAMs will join techniques for effluent transport and transformation analyses (ETTA's). Together

TABLE 75. ADJUSTED ORDERING NUMBERS FOR SEVERAL INORGANICS AND ORGANICS

Substance	Adjusted ordering no.
Beryllium	16,000,000
Benzo(a)pyrene	3,314,500
Dibenz(a,h)anthracene	754,833
7,12-Dimethylbenz(a)anthracene	272,809
N-Nitrosodimethylamine	59,053
3-Methylcholanthrene	18,683
Cadmium	7,329
Chromium	7,327
Selenium	6,426
N,N'Dimethylhydrazine	2,208
Cobalt	1,682
Dibenz(a,i)pyrene	1,612
Benz(a)anthracene	1,562
Dibenz(c,g)carbazole	679
Aminotoluenes	638
N-Nitrosodiethylamine	577
Nickel	477
2-Aminonaphthalene	423
Dibenz(a,h)acridine	312.4
Dibenz(a,j)acridine	284
Ethylenimine	210.6
Lead	136
1-Aminonaphthalene	124
Diazomethane	78
Benzo(b)fluoranthene	78
Dibenzo(a,l)pyrene	64.6
4-Aminobiphenyl	54
4-Nitrobiphenyl	54
Phenanthrene	44
Indeno(1,2,3-cd)pyrene	43

(continued)

TABLE 75. (continued)

Substance	Adjusted ordering no.
Formaldehyde	42.7
Methyl chrysenes	39
Tetraethyl lead	36
p-Dimethylaminoazobenzene	35
Chrysene	31.5
Picene	28
Nickel carbonyl	26
Benzo(e)pyrene	23
Nickelocene	20.2
Copper 8-hydroxyquinoline	20
Dibenzo(a,h)pyrene	18.9
Dibenzo(a,g)carbazole	11.6
Benzo(j)fluoranthene	10.8
Hydrazine	10.6
Mercury	10.6
2,4-Dichlorophenol	10
Dibenz(a,c)anthracene	7.1
Benz(c)acridine	6.67
Indole	6.5
Dibenz(a,i)carbazole	6
1-Chloro-2,3-epoxypropane	4.3
Phthalate esters	4.3
Benzo(g)chrysene	4.3
Benzidine	3.5
Dibenz(c,h)acridine	3.06
Benzo(c)phenanthrene	2.5
-Chlorotoluene	1.9
Silver	1.7
Anthracene	1.3
Naphthalene	1.2
Monomethylhydrazine	1
Pyrene	0.3

they are intended to provide a coarse screening of effluent stream impact for use in environmental assessments.

The simplest Source Analysis Model, the SAM/IA, is designed for rapid screening with no effluent transport and transformation analysis. Rapid screening of the potential degree of hazard and the rate of discharge of toxic pollutants may occur at any level or depth of chemical and physical analysis.

In the SAM/IA, waste streams from any process or applicable controls are not assumed to interact with the external environment (i.e., transport of the components in the waste stream to the external environment occurs without transformation of these components). No assumption is made about pollutant-specific dispersion, but it is assumed that such dispersion from the source to a receptor would, in almost all cases, be equal to, or greater than, the safety factors normally applied to acute (short-term exposure) toxicity data to convert them to estimated safe low-level, longer-term chronic ambient exposure levels.

SAM/IA thus:

- Is on a waste stream concentration basis
- Uses only one potential assessment alternative (the MATE)
- Does not include transport/transformation analysis
- Includes only degree of hazard/toxic-unit discharge calculations.

Such rapid screening requires understanding of the assumptions being made. These assumptions include:

- The approximately 650 substances currently in the MEG list, or soon to be added, are the only components of a waste stream which need to be included. Unknown components may be sources of environmental impact which are modified or modifiable by the control technology, and therefore Level 1 bioassay results will be important as a companion data base for interpretation of SAM/IA results.

- Dispersion of effluents will be adequate and will also offset any transformation to more toxic substances.

- The MATE values (or the basic data on which they are based) are adequate.

- No synergistic or non-additive effects are considered. The bioassay results are an important addition to the screening which will improve this area.

These assumptions are inherent to SAM/IA. No provision has been made for modification of the SAM/IA calculation method for specialized circumstances. In many cases the assumptions are conservative. However, these factors should be kept in mind in evaluating the need for more detailed assessment.

In SAM/IA, major simplifying assumptions have been made about pollutant transport and transformation in the environment prior to impact on a receptor. The criteria against which pollutant concentrations are judged have also been subject to simplifying assumptions. As a result, SAM/IA is designed for use by experienced and qualified project officers and environmental assessment contractor personnel who will, on a case-by-case basis, review these assumptions to ensure the correct application of the model. In addition, at the time of this report, many pollutants exist for which MATEs have not yet been established. The user must, therefore, exercise judgment in flagging these omissions and bringing them to the attention of the EPA in terms of:

- Their importance of the particular environmental assessment being conducted
- Requirements for the continuing development of additional MATE values.

5.1.2.1 SAM/IA Calculation Procedure

The steps included in the SAM/IA calculation procedure are as follows:

- Identify specific sources within the overall system or process.
- Identify the various waste streams from that source. Each gas, liquid, or solid waste discharge is included as a separate waste stream.
- Determine the concentration of each sample fraction (Level 1) or specific pollutant species (Level 2) to be considered in each waste stream. In Level 1 assessments the set of species potentially present which would lead to hazard is established at this point for each sample fraction.

- Each sample fraction or specific pollutant concentration in a given waste stream is then divided by its corresponding health-based MATE if this value is available. This quantity is, henceforth, called a "Potential of Hazard." A second quotient is formed using the corresponding ecological MATE. For example, let us assume the concentration of phenol in the aqueous waste stream from the proposed SRC facility will average 0.4 mg/l. The MATE based on health effects is 5.0 μg/l. Thus, the Potential Degree of Hazard based on health effects is 400 ÷ 5 = 80. Obviously, a Potential Degree of Hazard value greater than one (1) indicates that the pollutant concentration in a particular waste stream is greater than the corresponding MATE and, therefore, may cause environmental problems. Thus, phenols in the aqueous waste stream in this example may represent a significant environmental problem.

- At this point, each pollutant entry whose health or ecological potential Degree of Hazard is greater than unity is flagged. These flags have been put on the form specifically for later ease in spotting potential problem pollutants.

- The final calculation for each pollutant species or small fraction in each stream takes the product of its Potential Degree of Hazard and the waste stream flowrate to establish health (or ecological) Potential Toxic Unit Discharge Rates (PTUDR).

- The total stream Potential Degree of Hazard is then calculated as the sum of the health or ecological Potential Degree of Hazard for each pollutant.

Further, the total stream PTUDR is calculated by adding the individual pollutant entry Potential Toxic Unit Discharge Rates.

- Potential Degrees of Hazard and TUDRs are then grouped and totaled by gaseous, water, and solid waste streams.

- Finally, if a Level 1 assessment is being performed, any additional data which can be used to rule out the presence of a chemical species is noted.

It should be noted that the third step requires an enumeration of all of the components of a given effluent stream which are to be considered. If a component is not included in the enumeration, any environmental impact which results from its discharge will not be included in the results.

SAMs can be used to do one or more of the following:

- Rank waste streams - in this application, the SAM is used to compare the toxic unit rate of discharge of each waste stream; these toxic unit summations can then be ranked by magnitude. Examination of the relative magnitudes generated by different streams immediately shows the relative hazard of the different waste streams. Unfortunately, this summation as yet does not indicate absolutely if the waste stream will be environmentally hazardous.

- Establish specific Level 2 and additional Level 3 sampling and analysis priorities in performing environmental assessments.

- Determine problem pollutants and pollutant priorities. In this application, use of the SAM can lead to an understanding of which pollutants are most likely to cause major environmental impact because they remain poorly controlled under all equipment options currently available.

- Determine which control technology options are the most effective. In this application, the SAM is used to examine a given process stream with first one and then another control approach. The impact of alternative control equipment choices can be compared on the basis of:

    - The differing reductions which can be expected to occur in the original process streams pollutants

    - The ways in which concentration of certain pollutants into particular control equipment waste streams will occur.

- Determine the need for control/disposal technology development.

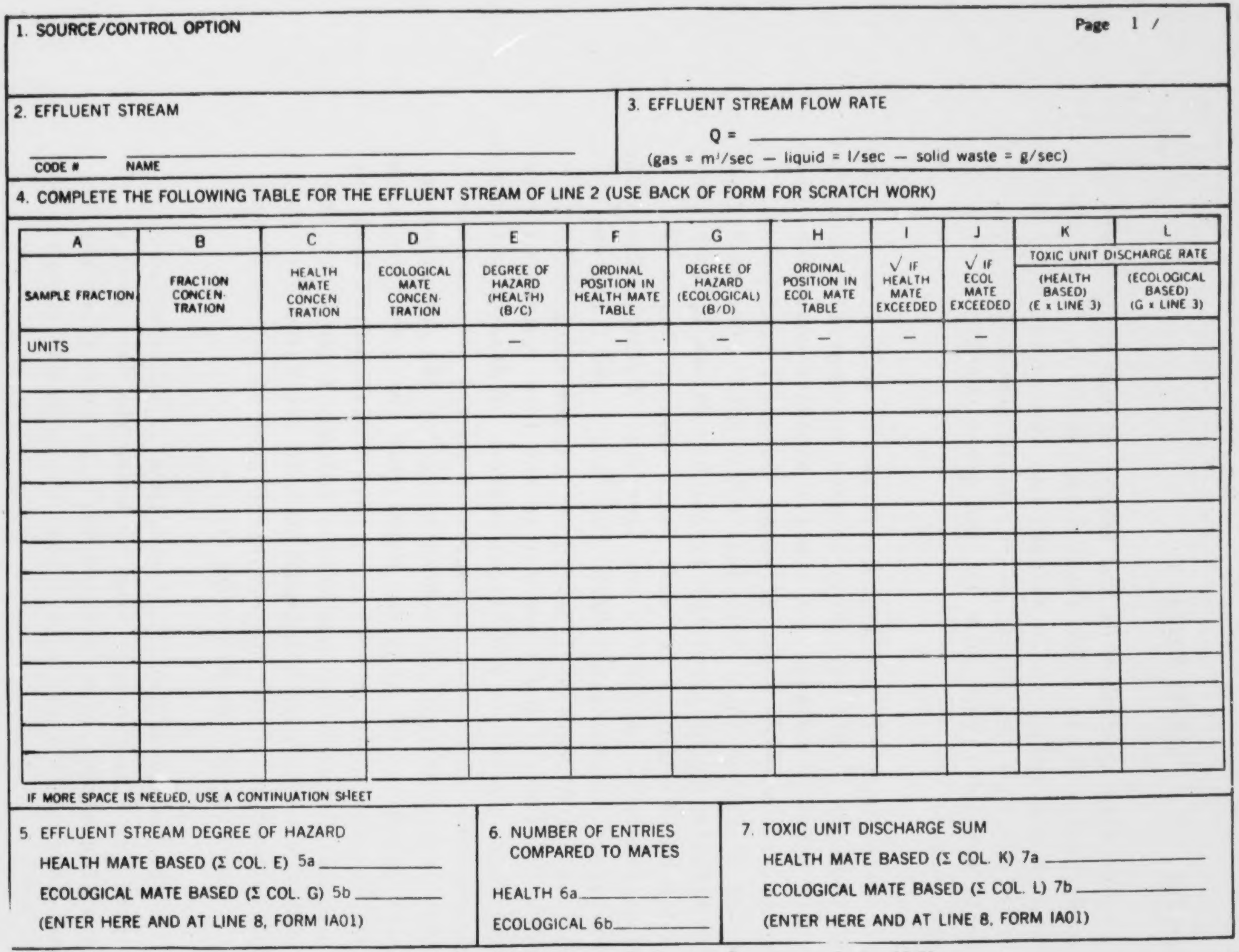
The SAM/IA format will ordinarily be used for rapid screening of the difference between an uncontrolled or poorly controlled process and the results of the application of various control options. Thus, it will ordinarily be applied to confined or ducted sources.

5.1.2.2 SAM/IA Format

The data generated by the SAM/IA method is recorded on two different forms. The first form (which is filled out for each individual waste stream) has two variations. Both variations show the source of the waste stream (Box 1), identifies the stream (Box 2), and gives the stream flow rate (Box 3).

An example of the first variation of this form is found in Figure 58. This variation is used to treat the data from a Level 1 analysis. A Level 1 analysis quantifies only groups of compounds (identified as "Sample Fractions" in Column A) rather than individual components. Column B shows the relative quantity of the fraction. Column C lists the health-based MATE for the most toxic compound known or suspected to be present in the fraction. Column D lists the corresponding ecological MATE. Columns E and G are the corresponding Degrees of Hazard calculated using these MATEs. Columns I and J are put in the form specifically to flag those health or ecological Degrees of Hazards which are greater than unity (1). A Degree of Hazard greater than unity indicates that the concentration of the pollutant in question is greater than the MATE; this fact, in turn, shows that the MEG approach indicates that environmental harm may be expected from this component. Columns K and L are the TUDRS for each fraction; these numbers are calculated by multiplication of the appropriate Degree of Hazard by the Effluent Stream Flow Rate (Box 3).

The second variation of the form is illustrated in Figure 59. This form is used to treat the data from a Level 2 analysis. The Level 2 analysis quantifies the individual pollutants rather than the compound groups. The



1. SOURCE/CONTROL OPTION

Page 1 /

2. EFFLUENT STREAM

CODE # ______ NAME ______________________

3. EFFLUENT STREAM FLOW RATE

Q = ______________________

(gas = m³/sec — liquid = l/sec — solid waste = g/sec)

4. COMPLETE THE FOLLOWING TABLE FOR THE EFFLUENT STREAM OF LINE 2 (USE BACK OF FORM FOR SCRATCH WORK)

A	B	C	D	E	F	G	H	I	J	K	L
										TOXIC UNIT DISCHARGE RATE	
SAMPLE FRACTION	FRACTION CONCENTRATION	HEALTH MATE CONCENTRATION	ECOLOGICAL MATE CONCENTRATION	DEGREE OF HAZARD (HEALTH) (B/C)	ORDINAL POSITION IN HEALTH MATE TABLE	DEGREE OF HAZARD (ECOLOGICAL) (B/D)	ORDINAL POSITION IN ECOL MATE TABLE	√ IF HEALTH MATE EXCEEDED	√ IF ECOL MATE EXCEEDED	(HEALTH BASED) (E x LINE 3)	(ECOLOGICAL BASED) (G x LINE 3)
UNITS				—	—	—	—	—	—		

IF MORE SPACE IS NEEDED, USE A CONTINUATION SHEET

5. EFFLUENT STREAM DEGREE OF HAZARD

HEALTH MATE BASED (Σ COL. E) 5a ____________

ECOLOGICAL MATE BASED (Σ COL. G) 5b ____________

(ENTER HERE AND AT LINE 8, FORM IA01)

6. NUMBER OF ENTRIES COMPARED TO MATES

HEALTH 6a ____________

ECOLOGICAL 6b ____________

7. TOXIC UNIT DISCHARGE SUM

HEALTH MATE BASED (Σ COL. K) 7a ____________

ECOLOGICAL MATE BASED (Σ COL. L) 7b ____________

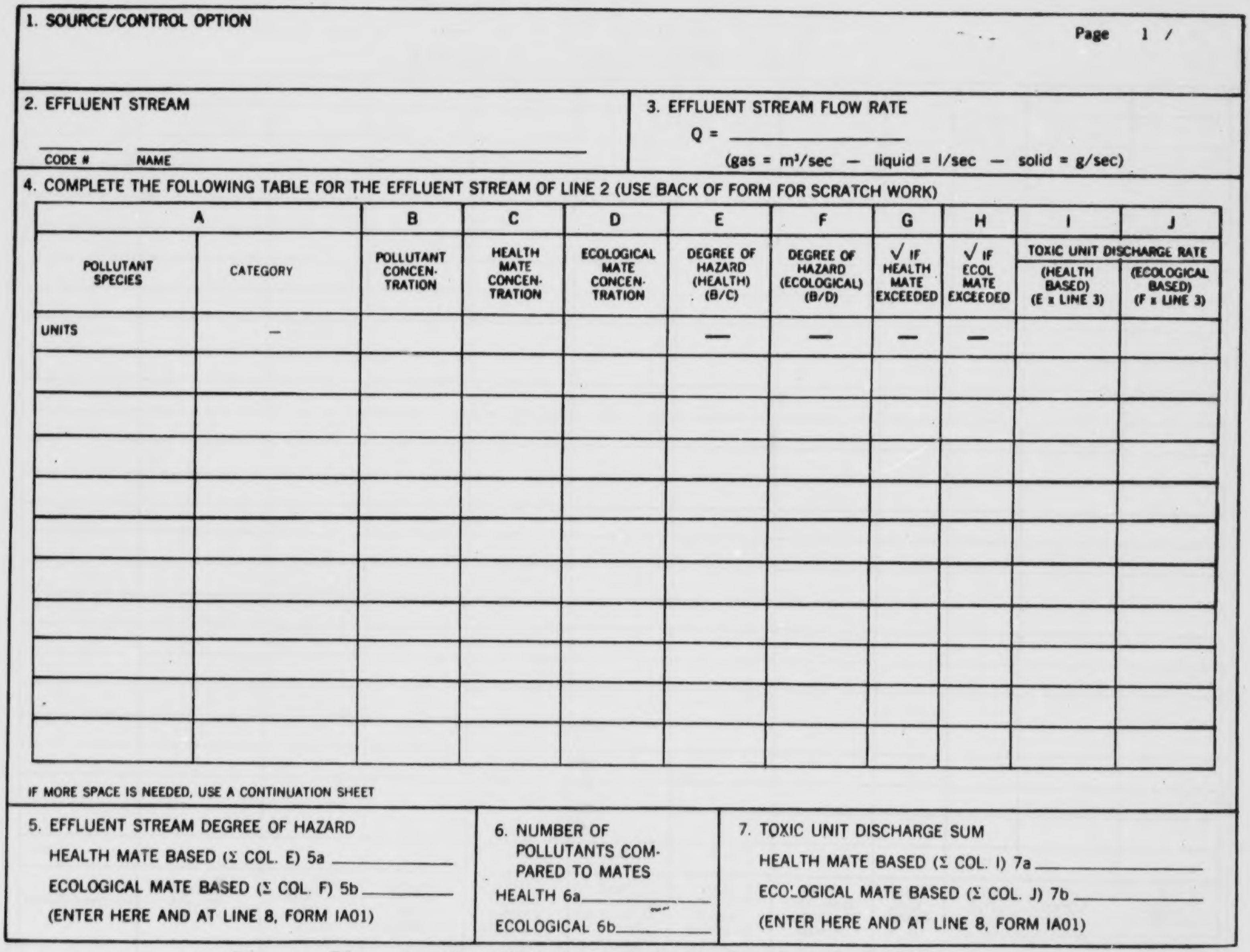
(ENTER HERE AND AT LINE 8, FORM IA01)

Figure 58. Sample SAM/IA worksheet for Level 1 (96)

SOURCE/CONTROL OPTION ______ EFFLUENT STREAM NO. ______

A	B	C	D	E	F	G	H	I	J	K	L
SAMPLE FRACTION	FRACTION CONCENTRATION	HEALTH MATE CONCENTRATION	ECOLOGICAL MATE CONCENTRATION	DEGREE OF HAZARD (HEALTH) (B/C)	ORDINAL POSITION IN HEALTH MATE TABLE	DEGREE OF HAZARD (ECOLOGICAL) (B/D)	ORDINAL POSITION IN ECOL. MATE TABLE	√ IF HEALTH MATE EXCEEDED	√ IF ECOL. MATE EXCEEDED	TOXIC UNIT DISCHARGE RATE	
										(HEALTH BASED) (E x LINE 3)	(ECOLOGICAL BASED) (G x LINE 3)
UNITS				—	—	—	—	—	—		

Figure 58. (continued) (96)



1. SOURCE/CONTROL OPTION

Page 1 /

2. EFFLUENT STREAM

CODE # ____ NAME ____

3. EFFLUENT STREAM FLOW RATE

Q = ____

(gas = m³/sec — liquid = l/sec — solid = g/sec)

4. COMPLETE THE FOLLOWING TABLE FOR THE EFFLUENT STREAM OF LINE 2 (USE BACK OF FORM FOR SCRATCH WORK)

A		B	C	D	E	F	G	H	I	J
									TOXIC UNIT DISCHARGE RATE	
POLLUTANT SPECIES	CATEGORY	POLLUTANT CONCENTRATION	HEALTH MATE CONCENTRATION	ECOLOGICAL MATE CONCENTRATION	DEGREE OF HAZARD (HEALTH) (B/C)	DEGREE OF HAZARD (ECOLOGICAL) (B/D)	√ IF HEALTH MATE EXCEEDED	√ IF ECOL MATE EXCEEDED	(HEALTH BASED) (E x LINE 3)	(ECOLOGICAL BASED) (F x LINE 3)
UNITS	—				—	—	—	—		

IF MORE SPACE IS NEEDED, USE A CONTINUATION SHEET

5. EFFLUENT STREAM DEGREE OF HAZARD

HEALTH MATE BASED (Σ COL. E) 5a ____

ECOLOGICAL MATE BASED (Σ COL. F) 5b ____

(ENTER HERE AND AT LINE 8, FORM IA01)

6. NUMBER OF POLLUTANTS COMPARED TO MATES

HEALTH 6a ____

ECOLOGICAL 6b ____

7. TOXIC UNIT DISCHARGE SUM

HEALTH MATE BASED (Σ COL. I) 7a ____

ECOLOGICAL MATE BASED (Σ COL. J) 7b ____

(ENTER HERE AND AT LINE 8, FORM IA01)

Figure 59. Sample SAM/IA worksheet for Level 2 (96)

SOURCE/CONTROL OPTION ____________ EFFLUENT STREAM NO. ________

A		B	C	D	E	F	G	H	I	J
									TOXIC UNIT DISCHARGE RATE	
POLLUTANT SPECIES	CATEGORY	POLLUTANT CONCENTRATION	HEALTH MATE CONCENTRATION	ECOLOGICAL MATE CONCENTRATION	DEGREE OF HAZARD (HEALTH) (B/C)	DEGREE OF HAZARD (ECOLOGICAL) (B/D)	√ IF HEALTH MATE EXCEEDED	√ IF ECOL MATE EXCEEDED	(HEALTH BASED) (E x LINE 3)	(ECOLOGICAL BASED) (F x LINE 3)
UNITS	—				—	—	—	—		

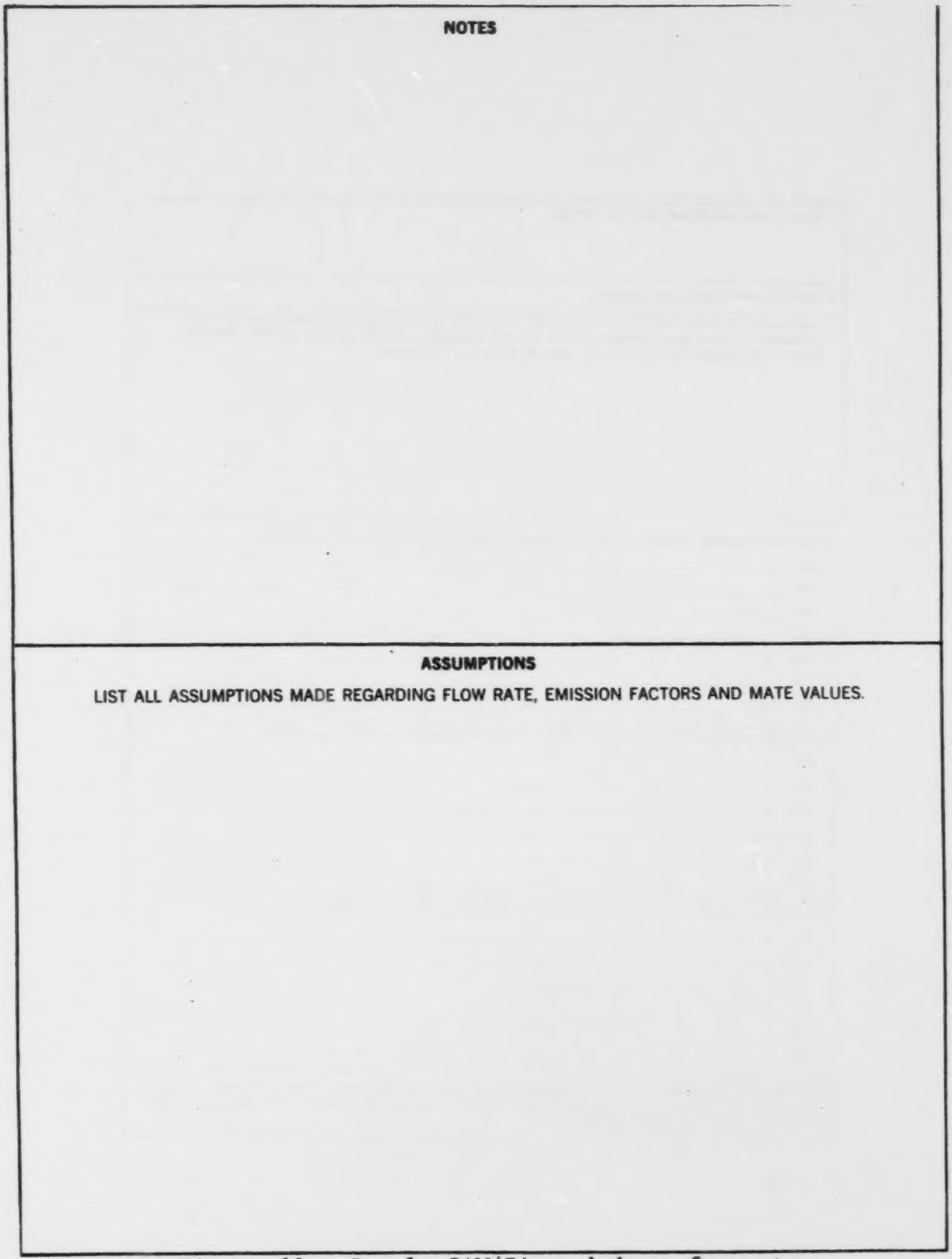
Figure 59. (continued) (96)

first three boxes of this variation of this form are analogous to the first variation.

Box 4 contains much information including each individual pollutant found in the stream (Box 4A), the MEG category to which this pollutant belongs (Box 4A), the concentration of this pollutant in the stream (Box 4B), the health-based and ecological-based MATE for this pollutant (Columns C and D), and the health-and ecological-based Degrees of Hazard (Columns E and F). Columns G and H of the fourth box are placed on the form specifically to flag which health- or ecological-Degree of Hazard is greater than unity. Columns I and J of Box 4 are the Toxic Unit Discharge Rates for each pollutant quantified for which MATEs are available.

The last three boxes (5 through 7) of each variation are exactly analogous. Box 5 shows the sum of the health- and ecological-based Degrees of Hazard for all the pollutants for which this calculation was possible. Box 6 was placed on the form specifically to show the number of pollutants for which the health- and ecological-based Degrees of Hazards could be calculated. Box 7 shows the Toxic Unit Discharge Sum, which is the sum of the Toxic Unit Discharge Rates for all the pollutants for which the Degree of Hazard (health and ecological based) could be calculated. The Toxic Unit Discharge Sum is quite useful in determining the relative toxicity of two streams but it has not, as yet, been correlated to prediction of absolute environmental hazard. Both variations have a page with boxes for notes and assumptions (Figure 60).

The second form, called the SAM/IA Summary Sheet, is shown in Figure 61. This form summarizes the data from the forms shown in Figures 58 and 59 which have been prepared

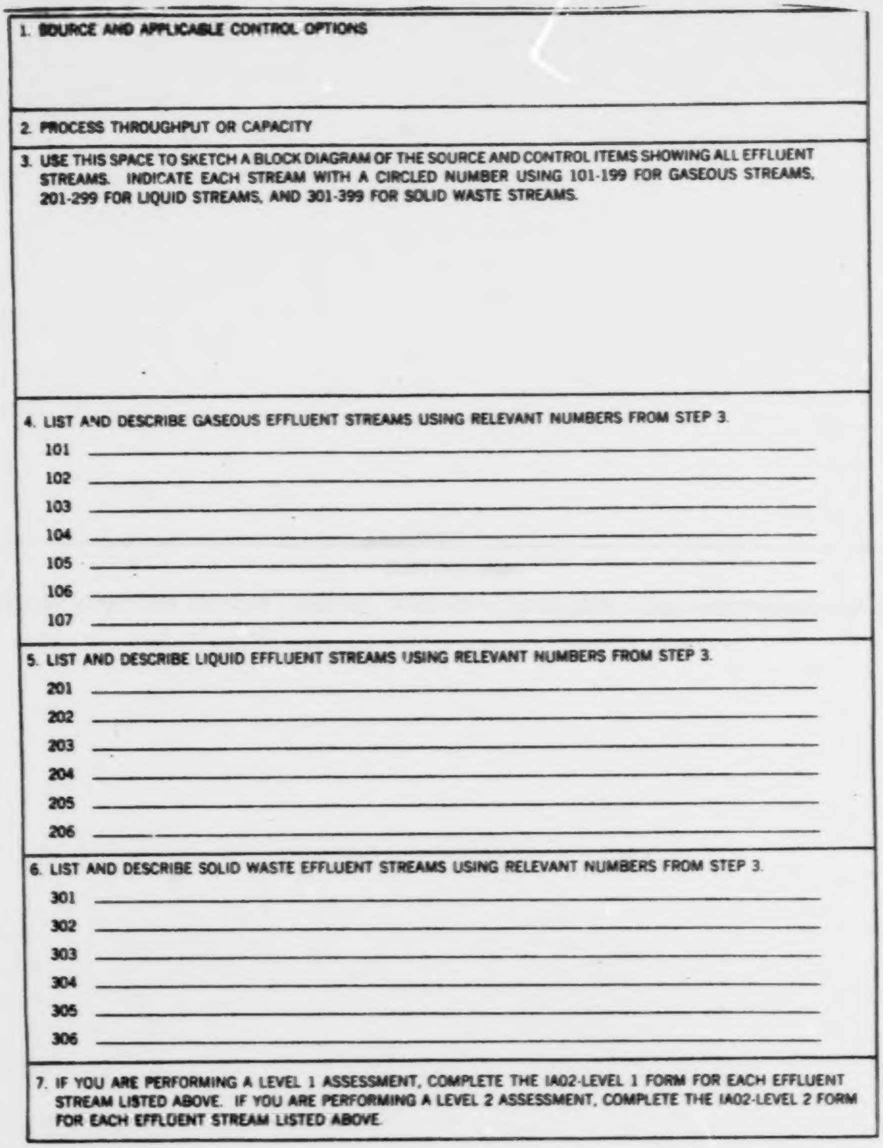


NOTES

ASSUMPTIONS

LIST ALL ASSUMPTIONS MADE REGARDING FLOW RATE, EMISSION FACTORS AND MATE VALUES.

Figure 60. Sample SAM/IA worksheet for notes and assumptions (96)



1. SOURCE AND APPLICABLE CONTROL OPTIONS

2. PROCESS THROUGHPUT OR CAPACITY

3. USE THIS SPACE TO SKETCH A BLOCK DIAGRAM OF THE SOURCE AND CONTROL ITEMS SHOWING ALL EFFLUENT STREAMS. INDICATE EACH STREAM WITH A CIRCLED NUMBER USING 101-199 FOR GASEOUS STREAMS, 201-299 FOR LIQUID STREAMS, AND 301-399 FOR SOLID WASTE STREAMS.

4. LIST AND DESCRIBE GASEOUS EFFLUENT STREAMS USING RELEVANT NUMBERS FROM STEP 3.

101 ____________________

102 ____________________

103 ____________________

104 ____________________

105 ____________________

106 ____________________

107 ____________________

5. LIST AND DESCRIBE LIQUID EFFLUENT STREAMS USING RELEVANT NUMBERS FROM STEP 3.

201 ____________________

202 ____________________

203 ____________________

204 ____________________

205 ____________________

206 ____________________

6. LIST AND DESCRIBE SOLID WASTE EFFLUENT STREAMS USING RELEVANT NUMBERS FROM STEP 3.

301 ____________________

302 ____________________

303 ____________________

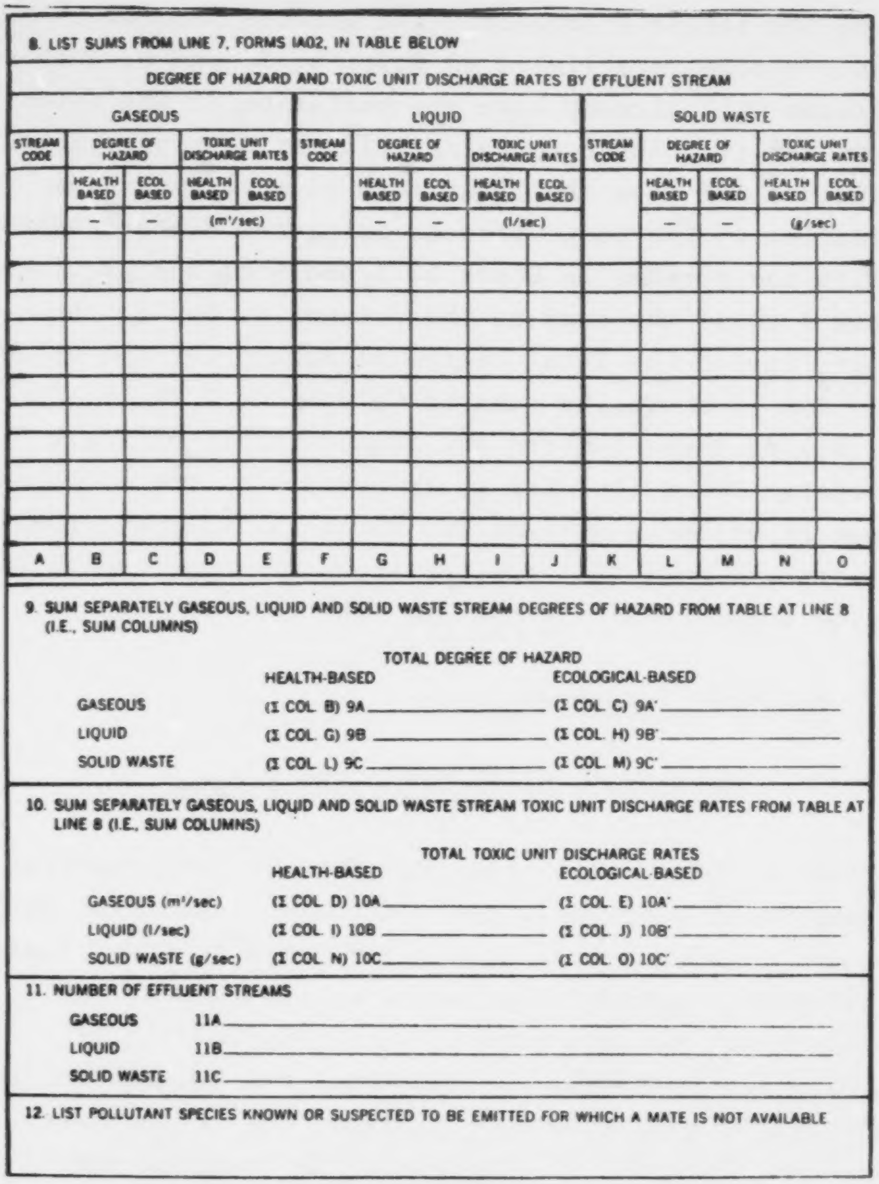
304 ____________________

305 ____________________

306 ____________________

7. IF YOU ARE PERFORMING A LEVEL 1 ASSESSMENT, COMPLETE THE IA02-LEVEL 1 FORM FOR EACH EFFLUENT STREAM LISTED ABOVE. IF YOU ARE PERFORMING A LEVEL 2 ASSESSMENT, COMPLETE THE IA02-LEVEL 2 FORM FOR EACH EFFLUENT STREAM LISTED ABOVE.

Figure 61. Sample SAM/IA summary sheet, Side 1 (96)



8. LIST SUMS FROM LINE 7, FORMS IA02, IN TABLE BELOW

DEGREE OF HAZARD AND TOXIC UNIT DISCHARGE RATES BY EFFLUENT STREAM

GASEOUS					LIQUID					SOLID WASTE				
STREAM CODE	DEGREE OF HAZARD		TOXIC UNIT DISCHARGE RATES		STREAM CODE	DEGREE OF HAZARD		TOXIC UNIT DISCHARGE RATES		STREAM CODE	DEGREE OF HAZARD		TOXIC UNIT DISCHARGE RATES	
	HEALTH BASED	ECOL BASED	HEALTH BASED	ECOL BASED		HEALTH BASED	ECOL BASED	HEALTH BASED	ECOL BASED		HEALTH BASED	ECOL BASED	HEALTH BASED	ECOL BASED
	—	—	(m^3/sec)			—	—	(l/sec)			—	—	(g/sec)	
A	B	C	D	E	F	G	H	I	J	K	L	M	N	O

9. SUM SEPARATELY GASEOUS, LIQUID AND SOLID WASTE STREAM DEGREES OF HAZARD FROM TABLE AT LINE 8 (I.E., SUM COLUMNS)

	TOTAL DEGREE OF HAZARD HEALTH-BASED	ECOLOGICAL-BASED
GASEOUS	(Σ COL. B) 9A ______	(Σ COL. C) 9A' ______
LIQUID	(Σ COL. G) 9B ______	(Σ COL. H) 9B' ______
SOLID WASTE	(Σ COL. L) 9C ______	(Σ COL. M) 9C' ______

10. SUM SEPARATELY GASEOUS, LIQUID AND SOLID WASTE STREAM TOXIC UNIT DISCHARGE RATES FROM TABLE AT LINE 8 (I.E., SUM COLUMNS)

	TOTAL TOXIC UNIT DISCHARGE RATES HEALTH-BASED	ECOLOGICAL-BASED
GASEOUS (m^3/sec)	(Σ COL. D) 10A ______	(Σ COL. E) 10A' ______
LIQUID (l/sec)	(Σ COL. I) 10B ______	(Σ COL. J) 10B' ______
SOLID WASTE (g/sec)	(Σ COL. N) 10C ______	(Σ COL. O) 10C' ______

11. NUMBER OF EFFLUENT STREAMS

GASEOUS 11A ______

LIQUID 11B ______

SOLID WASTE 11C ______

12. LIST POLLUTANT SPECIES KNOWN OR SUSPECTED TO BE EMITTED FOR WHICH A MATE IS NOT AVAILABLE

Figure 61. (continued) (96)

for each waste stream. It reiterates the source and applicable control options (Box 1), shows the total process throughput capacity for the entire facility (Box 2), and gives a diagram of the facility (Box 3). The gaseous, aqueous, and solid waste streams are listed in Boxes 4, 5, and 6; each of these streams will already have one variation of the forms filled out for it. Box 8 contains information transcribed from boxes 5 and 7 from the first form as well as stream identification of the waste streams using the numbers associated with the streams in Boxes 4, 5 and 6 of the previous page. Box 9 shows the sums of the columns in Box 8; the numbers are called the Total Degree of Hazard for the whole process. Box 10 shows the sums of Columns D, I, N, E, J, and O of Box 8; these numbers are called the Total Toxic Unit Discharge Rates (for the whole process). Box 11 shows the number of effluent streams for which analysis was possible. Box 12 lists the pollutant species known or suspected to be emitted for which a MATE is not available.

5.1.3 Bioassay Interpretations

5.1.3.1 Objectives of the EPA/IERL Program

The major objective of the EPA/IERL/RTP environmental source assessment program is the control of industrial emissions to meet environmental or ambient goals that set limits to the release of potentially hazardous substances. An important adjunct to this effort is the application of various bioassay protocols to industrial raw materials (feed streams) used in synthetic fuel systems, and to multimedia waste streams, in order to complement the physical and chemical data and to ensure that a comprehensive environmental assessment is made.

The IERL/RTP has developed a three-phased sampling and analytical approach to environmental source assessments, as follows (97):

- Level 1 - provides a set of samples which are used to represent the "average" composition gaseous, liquid and solid waste streams, and conducts biological and chemical assays via prescribed protocols
- Level 2 - confirms Level 1 results and makes a more detailed and valid characterization of the biological effects of the more hazardous streams
- Level 3 - monitors a limited number of selected hazardous substances and accurately defines the chronic sublethal effects of selected compounds.

Details on the strategy of the phased approach and the Level 1 multimedia sampling and analysis procedures are reported elsehwere (97).

5.1.3.2 Summary of Current EPA/IERL Bioassay Protocols

Short-term bioassays employing yeast, bacterial, and mammalian cells, in vitro, are now receiving prime consideration in establishing acute toxicity and mutagenicity, because these systems appear relatively free of the disadvantages inherent in the use of whole animal studies. An important aspect of current efforts is the recognition that the waste streams from advanced fossil fuels utilization are generally entities of poorly defined and continuously changing chemical (and physical) composition (98). Furthermore, the results of bioassays may be invalidated if, during sample generation, storage and handling the inorganic/organic constituents undergo changes which lead to the modification of the biotest system (98). Chemical and physical assays should be used to substantiate the occurrence of such changes before drawing conclusions from the bioassay data. In spite of these and other complications, it is believed that bioassay protocols have merit in the assessment of complex mixtures where synergisms and antagonisms may modify (positively or negatively) the toxicity, mutagenicity, and carcinogenicity of individual components of the waste streams. Results from these short-term (acute toxicity) tests must be backed-up by data obtained from long-term (chronic toxicity) tests whose aim is to define the limits (upper and lower) of exposure that can be tolerated by living systems.

Some of the more useful (Level 1) bioassays in use or considered for use by EPA, are shown in Table 76. Level 1 bioassays are classified as Ecological Tests (6 in number) and Health Effects Tests (3 in number). Unless the approximate toxicity of an effluent is already known, or the sample size is limiting, it is usually necessary to initially conduct range-finding tests covering the entire range of zero to 100 percent effluent using five widely spaced (geometric) effluent concentrations. These tests are needed to establish the best range of effluent concentration in terms of the specific test system. The exact tests are still being evaluated for additions, deletions, and changes. The Ecological and Health Effects Tests are characterized as follows (97).

TABLE 76. EPA LEVEL 1 BIOASSAYS (99)

	Health Bioassays			Ecological Bioassays			
				Aquatic	Terrestrial		
	Mutagenesis	Toxicity	Whole Animal		Plant	Soil	Animal
	Ames	CHO, RAM, WI-38	Roden Acute Toxicity	Fresh water(1): a) Algal b) Daphnia Mogna c) Fathead minnow Salt water(1): a) Algal b) Grass shrimp c) Sheepshead minnow	Stress ethylene/foliar injury response See germination/seedling growth test	Soil respiration Nitrogen fixation	Insect bioassay (honeybee or fruitfly)
Type Sample:							
Liquids	X	X	X	X	---	(3)	X
Solids	X	X	X	X	---	(3)	X
Solid leachate	X	(2)	(2)	(2)	---	(3)	---
Fast particulate	X	---	---	---	---	---	---
Fast organics	X	---	---	---	---	---	---
Gases	---	---	---	---	(3)	---	X

Legend: X = included, - = omitted

(1) Normally either fresh or salt water organisms are tested, not both.
(2) These bioassays can be raw if there will be runoff to the environment.
(3) These bioassays are raw subject to considerations of type of system and potential impacts on plants or soil.

5.1.3.2.1 Health Effects Tests

Salmonella/Microsome Mutagenesis Assay (Ames) - The Ames test is used to screen complex mixtures or component fractions, thereby determining their potential mutagenicity. It has recently been demonstrated that most carcinogens act as mutagens. The Ames test has proven 90 percent accurate in detecting known carcinogens as mutagens.

Toxicity Assays - Cytotoxicity assays measure cellular metabolic impairment and death due to in vitro exposure of mammalian cell cultures to soluble and particulate toxicants. Level 1 cytotoxicity assays employ primary cultures of rabbit alveolar (lung) macrophages (RAM) and maintenance cultures of WI-38 human lung fibroblasts. Utilization of cytotoxicity bioassays has permitted ranking of toxic responses to a variety of industrial particulates collected by a cyclone sampler.

Acute In-Vivo Test In Rodents - This assay determines toxicological effects of unknown compounds on rats. To minimize costs, subject compounds are first tested for quantal response, over a 14 day test period with a test population consisting of 10 rats. In cases where death or severe toxicological effects are observed, a more extensive test is performed with a population of 80 rats, exposed to varied concentrations of the subject compound. Quantitative data on toxicological response is collected during the 14 day test period, including determination of LD_{50}.

5.1.3.2.2 Ecological Effects Tests

Freshwater Algal Assay: Bottle Test - This test may be used to quantify biological responses (as freshwater algal growth) to variations in concentrations of nutrients, and determines whether or not effluents are toxic to algae or inhibit their growth. The freshwater algal bioassay is based on the principle that algal growth rates are limited by the nutrient available in shortest supply, relative to the needs of the organism.

Marine Algal Bioassay - Selected species of marine algae are exposed to subject contaminants or wastewaters and monitored for growth response. Marine algae are the foundation of the food chain in ocean ecosystems. Introduction of pollutants to such systems can have various impacts of growth rates for the many species of marine algae, thereby producing undersired changes in the food chain and populations of other ocean species. Marine algal bioassays provide a tests index to identify potentially undesirable impacts.

Acute Static Bioassays with Freshwater Fish and Daphnia Magna - The vertebrate fathead minnow and invertebrate *Daphnia magna* are the representative freshwater organisms used in this bioassay. These aquatic organisms are used to integrate synergistic and antagonistic effects of all components of subject aqueous test samples during the period of exposure.

Static Bioassays with Marine Animals - Juvenile sheepshead minnow and adult grass shrimp are the respective vertebrate and invertebrate species employed for static bioassays on marine animals. This method has been used to rank the toxicity of industrial effluents relative to other marine animals.

Stress Ethylene/Foliar Injury Plant Response - This test is based on plant response to environmental stress involving the release of ethylene. Under normal conditions, plants produce low levels of ethylene. By exposing plants to gaseous emissions and measuring the rate of ethylene release relative to control (normal) conditions, the stress ethylene release attributable to the emission can be identified as a quantified response.

Seed Germination/Seedling Growth Tests - These tests evaluate toxic pollutants of environmental samples that inhibit seed germination and root elongation. The tests are particularly suited for aqueous effluents and aqueous leachates from solid samples, and have been validated for use by the Office of Toxic Substances.

Soil Respiration/Nitrogen Fixation Tests - These tests can be performed with both liquid and solid waste materials. They are especially useful in assessing potential impacts associated with transport and landfill disposal of such materials. The test is based on measurement of changes in respiration of carbon dioxide by microbial activity of the soil sample and the general ability of microbes to take up nitrogen surrogates.

Insect Bioassays - Insect bioassays are performed to measure the acute toxicity of solid, liquid or gaseous samples on sensitive insect species. The honeybee and fruitfly are currently under consideration as representative insect species for employment in Level 1 biological testing.

5.1.3.3 Extrapolation From Bioassay Results

The extrapolation of data derived from Level 1 assays (chemical, physical, and biological) to the environment requires an understanding of the limitations inherent to these techniques. For example, the Level 1 analyses simply provide a basis for differentiating the extremely hazardous waste streams from those which are less hazardous. Level 1 bioassays are limited to whole-sample testing of a set of samples, which represent the "average" composition of solid, liquid, and gaseous feed or waste streams. In this context, it is imperative that the investigator recognize that many of the waste streams under study may not only be rather poorly characterized, but also may display a continuously changing chemical and physical composition (97). Thus, the information obtained from the prescribed bioassay is strictly a function of the care and skill used in controlling and preparing the samples for analysis, and of the quality of the information obtained on these samples via the supportative chemical and physical assays (97).

The information gleaned from any one of the Level 1 bioassays is limited in scope and therefore requires that the minimal matrix of prescribed bioassays must be completed to permit a valid assessment of the test sample(s) (Level 1, 1978). The results of the Level 1 bioassays do not permit the identification of the cause of toxicity or mutagenicity, nor do they suggest the means of controlling or mitigating these deleterious effects (97). Level 1 bioassays have been selected because they are compatible with a broad spectrum of materials and because they have enough sensitivity to detect potentially harmful substances.

In general, the Level 2 bioassays will be selected on the basis of the results acquired from Level 1 analyses.

Greater emphasis at Level 2 is placed on confirming the Level 1 results, primarily through acquiring more representative samples, increasing the number of replicated samples, and carrying out more extensive statistical evaluations of the data. Suggested Level 2 health effects bioassays include *in vitro* and *in vivo* tests to confirm the potential toxicity or mutagenicity detected by Level 1 bioassays. Thus, in Level 2 bioassays, attention can be focused on specific fractions or discrete components of the multimedia waste streams, thereby increasing the cost and complexity of this phase (97). Examples of Level 2 ecological effects bioassays include: relative phytotoxicity of selected airborne pollutants; bioaccumulation, and biodegradation of discrete components.

The primary purpose of Level 3 tests is to accurately define the chronic sublethal effects of selected compounds and to monitor these substances in appropriate media. The monitoring activities referred to may include: source, ambient, and ecologic and human health effects monitoring. Suggested Level 3 health effects bioassays may include *in vivo* analyses for chronic toxicity, mutagenisis, carcinogenesis, teratogenesis, and metabolism. Examples of Level 3 ecological effects assays may include ecosystems analysis, mutagenicity tests on toxic substances removed by waste treatment facilities, and tests to establish the relative phytotoxicity of airborne toxicants of selected plant species (97).

5.1.3.3.1 Extrapolations

A major consideration in the establishment of the relative toxicities of various pollutants is whether bioassay results can be extrapolated to environmentally significant circumstances. Extrapolating laboratory data to man and other organisms in the environment requires great care. Susceptibility of animals to toxic agents may vary with the species of animal and sometimes with strains of the same species. Organisms may be exposed to the toxicants at levels much higher than those found in nature and organisms growing in nature under nutrient-limited conditions may be more susceptible to toxicity. The nonliving particulate matter in nature will adsorb some of the added pollutants, reducing toxicity. Experimental outcomes may depend upon dosing routes and regimes. The statistical significance of animal experiments may be doubtful because of the necessary limitations in the size of test groups. Also, the artificial laboratory system does not allow for the interactions and synergisms that occur in the natural and work environment (100,101).

The extrapolation of the toxicity of inorganic elements and compounds, based on laboratory data is complicated since the chemical form of a trace element depends on chemical and biological conversions in the environment (100). The toxicity of an inorganic element or compound is a function of several site specific factors and a number of receptor qualities, such as:

- Test species
- Temperature (102)
- Water hardness
- Turbidity
- Carbon dioxide content
- Dissolved oxygen

- Current velocity (97)
- Salinity
- Alkalinity (103)
- pH
- Stage of life cycle (102)
- Oxidation state or chemical form of the element (102,103)
- Route of entry
- Length of exposure
- Dietary content of interacting elements (104)
- Age and physical condition of test organisms
- Size of organisms
- Humidity (102)
- Previous exposure (105)
- Organic complexation changes bioavailability of trace elements (106)

Although many of these factors cannot be considered in laboratory bioassays, they can serve as points of departure in the design of long term population or ecosystem studies.

The applicability of results from animal studies of carcinogens to the prediction of cancer in humans will be used as an example of how laboratory toxicity studies can be extrapolated to the environment; this example has been studied extensively and is of interest because some of the SRC waste streams contain known carcinogens.

Marked differences in susceptibility to carcinogenic agents exist between species as well as between strains of the same animal species. For example, the site of origin and the histologic type of respiratory tract tumor depend on the species and strain of animal as well as the route of application and dose. Dose levels in animal experiments considerably exceed the natural levels experienced by humans.

Furthermore, the artificial laboratory system does not allow for the interactions and synergisms that occur in the natural and work environment. For instance, PAH carcinogensis is enhanced in animals when the PAH occurs in iron oxides and long-chain aliphatic hydrocarbons, but is inhibited by materials such as vitamin A and selenium (44).

At the heart of the problem of using data from studies in animals is the large doses they must be given to produce a response discernible above the background. Whether the response to lower doses progresses to zero asymtotically with the decreasing dosage, or whether it goes quickly to zero as the dose is lowered is unknown (107).

Low doses may be subjected to different pharmacokinetics than high doses. For example, furosemide, a diuretic, is excreted predominantly intact in the urine when low doses are given to patients. When high doses are administered, renal clearnace is overwhelmed causing a disproportionate increase in the formation of toxic metabolites which react covalently with macromolecules. In another example, bromobenzene is transformed in the liver to the chemically reactive bromobenzene-3,4-epoxide. This molecule is detoxified enzymatically by conjugation with glutathione. However, if large doses are administered, glutathione is depleted and the reactive metabolite reacts instead with other macromolecules (107).

Some criteria which indicate that nonlinear pharmacokinetics are applicable for describing the elimination of a chemical from the body are: (1) decline of the levels of the chemical in the body is not exponential; (2) the $t_{1/2}$ (biological halflife) increases with increasing dose; (3) the area under the plasma concentration versus time curve is not proportional to the dose; (4) the composition of the excretory products may be changed both quantitatively and qualitatively by dose; (5) competitive inhibition by other chemicals metabolized or actively transported by the same enzyme system is likely; (6) dose-response curves may show an unusually large increase in response with increasing dose, starting at the dose level where "saturation" effects become evident (107).

For the toxicologist, the dose-response curve is of particular importance in assessing the risk of adverse effects occuring at lower doses (107). The latency for the development of hepatic angioscarcoma in rats is respectively, 64, 70, 78, 81, 78, and 135 weeks for rats exposed to 10,000, 6000, 2400, 500, 250, and 50 ppm vinyl chloride. These results indicate that, at the low levels of exposure, the time required for induction exceeds considerably the mean life expectancy for rats (approximately 104 weeks). This is consistent with the work of others suggesting that multiples of a lifetime may be required for the expression of cancer in response to low doses of a carcinogen (107). Thus, extrapolation of the data obtained for rats below the range of exposures causing a discernible response may be expected to overestimate the projected incidence (107).

Recently, the members of an FDA panel on carcinogensis attempted to extrapolate from the results of a dose-response study, using high doses of a given chemical carcinogen and limited numbers of animals, to the dose at which the tumor incidence would be one in 100 million. They found that the value of this dose varied according to the type of mathematical treatment selected for the extrapolation. This variation was so great that they concluded that extrapolation from the observable range to a safe dose has many of the perplexities and imponderables of extrapolation from animals to man, and it would be imprudent to place excessive reliance on mathematical sleight of hand, particularly when the dose-response curves used are largely empirical descriptions, lacking any theoretical, physical, or chemical basis (108).

Table 77 lists chemical compounds which have been shown to be carcinogenic to both laboratory animals and man. Thus, there is a clear historical indication that if there is strong evidence that a chemical is carcinogenic in appropriate laboratory animal test systems, it must be treated as if it were carcinogenic in man (109).

TABLE 77. CHEMICALS FOR WHICH EVIDENCE EXISTS OF CARCINOGENICITY TO BOTH NONHUMAN AND HUMAN ANIMALS (109)

Aflatoxins
4-Aminobiphenyl
Asbestos
Benzidine
Bis(chlormethyl)ether
Cyclophosphamide
Diethylstilboestrol
Isopropyl oil
Melphalan
Mustard gas
2-Napthylamine
N,N-Bis(2-chloroethyl)-2-naphthylamine
Phenytoin
Soot, tars & oils (PAHs)
Vinyl chloride

It is important to note that 4-aminobiphenyl, diethylstilbestrol (DES), mustard gas, vinyl chloride and aflatoxins were shown to be carcinogenic in laboratory animals prior to evidence that they were carcinogenic in man. The carcinogens for which comparisons can be made are those already known to affect humans. In generalizing to other compounds, this selection may impose a bias, exaggerating the sensitivity of man relative to laboratory test systems. Other factors may introduce an opposite bias. For two carcinogens, vinyl chloride and DES, observations on man are for considerably less than a full lifetime so that the reported incidence may be a serious underestimate of the eventual total (110).

Some considerations which may argue for greater human sensitivity are listed below (110):

- Smaller animals tend to metabolize and excrete foreign organic chemicals more rapidly than do larger animals; therefore, higher body burdens develop in man over the years than develop in mice and rats in a two-year experimental period.

- Since chemically induced cancer is viewed as originating in one or a few cells, it is relevant that a human has hundreds of times more susceptible cells than a mouse or a rat.

- A latent period intervenes between the original carcinogenic stimulus and the eventual manifestation of cancer. The cells of smaller animals replicate themselves at perhaps twice the rate of cells of larger animals such as man, and latent periods are longer in large animals. The human lifespan, however, is 35 times that of the mouse or rat; and this may render man more susceptible.

- The lifetime rodent studies have serious statistical power problems as a result of the relatively small sample sizes that are dictated by economics. The inability of the screening experiments to detect tumor increases at sites that have low baseline tumor rates is of particular concern; even though small increases are difficult to detect, they might have a significant health impact. For example, with 50 control animals and 100 treated animals the probability (p) of detecting a tumor increase of 5 percent over background (e.g., 10 percent control, 15 percent treated) is less than 4 percent (using p less than 1 percent) (110).

- Inborn errors of metabolism (i.e., genetic defects) in humans can produce exaggerated toxicity of "broad categories of chemical pollutants, relative to test animals (111).

Table 78 shows the predicted human incidence based on animal experiments related to the actual incidence. This table indicates that materials which are carcinogenic in laboratory animals are quite likely to be carcinogenic in humans.

TABLE 78. RELATIONSHIP BETWEEN PREDICTED AND ACTUAL BEHAVIOR OF HUMAN CARCINOGENS

	Predicted Human Incidence Based on Most Sensitive Animal Species According to Existing Epidemiological Studies
Benzidine	same
Chloronaphazine	same
Cigarette smoke	same
Aflatoxin B_1	10 x greater
DES	50 x greater*
Vinyl chloride	500 x greater*

*Population still at risk

5.1.3.3.2 Cocarcinogens

Cocarcinogens are compounds which enhance the effect of carcinogens. By themselves they may not be carcinogenic but can promote multiplication of abnormal cells after initiation of the conversion of a normal cell to a malignant cell by a carcinogen. The fact that coal tar itself is more carcinogenic than known individual carcinogenic compounds, suggests the presence of cocarcinogens. In an experiment performed in 1967, Tye and Stemmer (44) removed the phenols from coal tar, similar to the phenols which comprise a major component of SRC process wastewaters and observed that the carcinogenic activity of the resulting material was significantly decreased. In 1969 Conzelman (44) discovered that the skin cancer-inducing activity of benzo(a)pyrene and of benzo(a)anthracene and known to be associated with SRC materials was increased 1000 times when n-dodecane was used as the solvent. In 1970, Laskin and coworkers (44) reported that inhaling benzo(a)pyrene alone did not produce lung cancer in rats, while inhaling sulfur dioxide in company with benzo(a)pyrene did produce cancerous tumors (44).

The carcinogenic potential of certain PAH is greater in solvents such as n-dodecane and dodecylbenzene than in hydrocarbons of low molecular weight. Hydrocarbons which increase the rate of cancer induction by a carcinogen are capable of preconditioning the skin of mice to render it more responsive to subsequent applications of a carcinogen. The acclerating solvents are effective promoters of carcinogenisis initiated by a single application of a carcinogenic material (44).

Some additional substances which are thought to have cocarcinogenic properties are phenols, long-chain hydrocarbons including cresols, nonionic detergents, phorbol, myristate, acetate, and anthralin (44). Among these substances phenols, cresols, and certain long-chain hydrocarbons are known to be associated with SRC materials and products.

5.1.3.3.3 Site-Specific Factors

The ambient concentration of a pollutant in the environment may affect the environmental hazard potential if the quantity of this pollutant is increased above a certain threshold by the amount in the effluent stream. For example, in the supernatant from the fly ash slurry prepared by Olsen and Warren (112), the concentration of fluoride was sufficient to cause mottling of children's teeth. This could be a problem especially if such a level of fluoride should enter the ground waters in the western United States already containing up to 15 ppm fluoride. These observations serve as a point of departure in emphasizing the crucial importance of considering site-specific factors in making comprehensive environmental assessments. Site-specific effects such as water hardness, turbidity, suspended sediments, current velocity, CO_2 and dissolved oxygen levels, salinity and pH can affect the toxicity of pollutants to aquatic organisms in unpredictable ways. With reference to terrestrial environments, one must contend with site-specific effects that include: the level of soil organic matter; the types of clay minerals; soil pH; soil aeration and temperature and the capacity of soil microbes to degrade and metabolize organic contaminants.

5.1.4 Joint Site Selection and Impact Assessment Methods

Justification for the joint use of site selection and impact assessment methodologies rests on the fact that it provides a basis for dealing with SRC systems on a holistic basis. The most relevant methods in current use for the screening and selection of potential SRC sites are discussed in Section 5.8.1. The most useful site selection protocols will include a series of successive evaluations of many potential sites extending from the generic to the site-specific, aimed at the generation of realistic environmental impact statements as required by the final regulations on EIS's issued recently by the Council on Environmental Quality (CEQ), effective July 31, 1979 (113).

Specific impacts occurring at a given SRC site may be assessed by use of an environmental matrix comparable to that shown in Figure 62. Impact models specific to any given impact (e.g., the expected loss of unique natural habitats) are recommended in order that each impact may be assessed independently of all other impacts. For example, the U.S. Department of Energy (DOE) used a community development program model to generically estimate the sociocultural end impacts resulting from the construction and operation of synfuels plants in the United States (114). Another example of a method for deriving a formalized, numerical ranking of environmental impacts is that reported by Ramsay (115). This method reportedly has the dual goal of not only locating power plants in different regions, but also of sequentially estimating the dollar value of environmental impacts in terms of the following environmental categories (115):

- Geology
- Meterology
- Population centers
- Seismology
- Hydrology
- Ecosystems
- Land use
- Overall costs

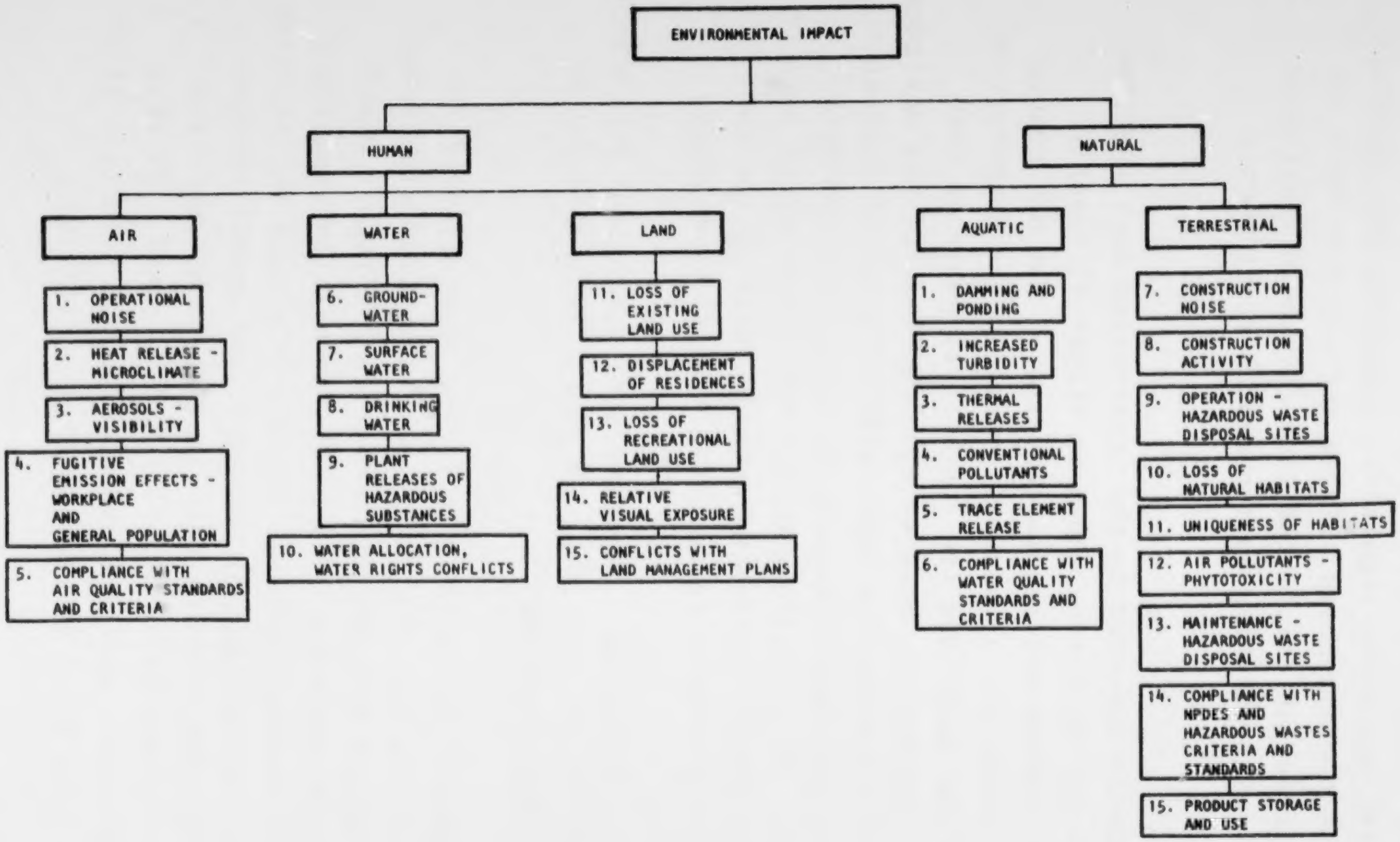

ENVIRONMENTAL IMPACT
HUMAN
NATURAL
AIR
WATER
LAND
AQUATIC
TERRESTRIAL
1. OPERATIONAL NOISE
2. HEAT RELEASE - MICROCLIMATE
3. AEROSOLS - VISIBILITY
4. FUGITIVE EMISSION EFFECTS - WORKPLACE AND GENERAL POPULATION
5. COMPLIANCE WITH AIR QUALITY STANDARDS AND CRITERIA
6. GROUND-WATER
7. SURFACE WATER
8. DRINKING WATER
9. PLANT RELEASES OF HAZARDOUS SUBSTANCES
10. WATER ALLOCATION, WATER RIGHTS CONFLICTS
11. LOSS OF EXISTING LAND USE
12. DISPLACEMENT OF RESIDENCES
13. LOSS OF RECREATIONAL LAND USE
14. RELATIVE VISUAL EXPOSURE
15. CONFLICTS WITH LAND MANAGEMENT PLANS
1. DAMMING AND PONDING
2. INCREASED TURBIDITY
3. THERMAL RELEASES
4. CONVENTIONAL POLLUTANTS
5. TRACE ELEMENT RELEASE
6. COMPLIANCE WITH WATER QUALITY STANDARDS AND CRITERIA
7. CONSTRUCTION NOISE
8. CONSTRUCTION ACTIVITY
9. OPERATION - HAZARDOUS WASTE DISPOSAL SITES
10. LOSS OF NATURAL HABITATS
11. UNIQUENESS OF HABITATS
12. AIR POLLUTANTS - PHYTOTOXICITY
13. MAINTENANCE - HAZARDOUS WASTE DISPOSAL SITES
14. COMPLIANCE WITH NPDES AND HAZARDOUS WASTES CRITERIA AND STANDARDS
15. PRODUCT STORAGE AND USE

Figure 62. Example of a hierarchical system for evaluating the impacts of construction and operation of synfuel plants

This effort is reportedly made somewhat easier by the existence of federal and state regulatory standards that must be met on a site-specific basis. These and other factors can effectively establish the bottom line for the overall cost of compliance with existing environmental requirements (115).

Attention is directed to the interesting fact that the impact assessment hierarchy shown in Figure 62 clearly embodies the general multimedia concerns of the MEG concept (air, water, land, etc.), with reference to the construction phase on the one hand, and the operational phase on the other hand. Implicitly, however, the MEG concept was designed largely for the testing and monitoring of point sources at operational pilot, demonstration, or commercial synfuels plants. Thus, the justification for the joint use of site selection and impact assessment methods rests on the fact that it provides a basis for dealing with the continuum:

- Site selection - construction; operation; postoperation during the 20 to 25 year lifetime of future synfuels systems.

What remains for the future is the adaptation of the MEG concept to include the entire continuum from site selection to an operational SRC demonstration plant that would, under realistic operating conditions, permit the assessment of health and ecologic hazards concurrently with the selection, testing, and the redesign of equipment and operating parameters at the same location (or site) where a commercial synfuels system may later be built and operated. In this context, the effort and cost expended on the selection of an appropriate site could be more readily justified.

5.2 Impacts on Air

Development and commercialization of Solvent Refined Coal Systems creates a concern regarding the introduction of air pollutants into the atmosphere. This section discusses pollutant concentrations in waste streams, their comparison to existing and proposed standards, and the projected impact of contaminants on ambient air quality, man and the environment.

5.2.1 Summary of Air Standards and Guidelines

5.2.1.1 Federal Requirements

The federal air regulations pertaining to the ambient atmosphere, workroom atmosphere, and source emission levels for specific pollutants relevant to coal liquefaction processes are summarized as follows:

Applicable regulated area	Title of standard
Ambient atmosphere	National Primary and Secondary Ambient Air Quality Standards
Workroom atmosphere	Occupational Safety and Health Administration Standards for Air Contaminants
Source emission level	National Emission Standards for Hazardous Air Pollutants
	New Stationary Source Performance Standards

A summary of the implications of these standards and their legislative basis is presented in the following subsections.

5.2.1.1.1 National Primary and Secondary Air Quality Standards

The National Primary and Secondary Air Quality Standards set the maximum ambient concentrations for oxidants, CO, NO_2, SO_2, nonmethane hydrocarbons, and particulate matter as shown in Table 79. Primary standards are set for the protection of health. Secondary standards are set for the protection of welfare which as defined "includes but is not limited to, effects on soils, water, crops, vegetation, manmade materials, and climate damage to and deterioration of property, and hazards to transportation, as well as effects on economic values and on personal comfort and well being" (116).

TABLE 79. NATIONAL PRIMARY AND SECONDARY AMBIENT AIR QUALITY STANDARDS

Constituent	Concentration (micrograms/m^3)	Remarks
Sulfur oxides	80	AAM**
primary	365	24 hr max*
	1300	3 hr max*
Particulates		
primary	75	AGM**
	260	24 hr max*
secondary	60	AGM**
	150	24 hr max*
Carbon monoxide		
primary	10,000	8 hr max*
secondary	40,000	1 hr max*
Photochemical oxidants		
primary and secondary	160	1 hr max*
Hydrocarbons		
primary and secondary	160	3 hr max*
Nitrogen dioxide		
primary and secondary	100	AAM**

Reference conditions: Temperature = 25°C = 77°F
Pressure = 760 mm Hg = 29.92 in Hg = 1 atmosphere

* Maximum value not to be exceeded more than once per year.
**AAM and AGM denote the annual arithmetic mean and the annual geometric mean, respectively.

5.2.1.1.2 New Stationary Source Performance Standards

New Stationary Source Performance Standards have been promulgated for a number of industries. This category of legislation prescribes standards of performance for sources for which construction is commenced after publication of applicable standards. Since there are no existing commercial coal liquefaction facilities, applicable regulations would be promulgated under this regulatory category. New Source Performance Standards (NSPS) for existing industries which have processes similar to those of a coal liquefaction facility are presented in Table 80.

The term "standard of performance" means a standard for emissions of air pollutants that reflects the degree of emission limitation achievable through the application of the best system of emission reduction, which (taking into account the cost of achieving such reduction) EPA determines has been adequately demonstrated. EPA has not attempted to define averages or representative emission rates. Consideration of cost is applied as a modifier to avoid extremes. According to the Committee on Public Works, "the technology must be available at a cost and at a time which the Administrator determines to be reasonable (123).

Individual standards are not intended to be protective of health or welfare effects; that is, they are not designed to achieve any air quality goals. The standards are designed to reflect the best technology for each individual source. The long-range goal and overriding purpose of the collective body of standards is to prevent new pollution problems from developing. To achieve this end, the standards must be an incentive for technological change, and the justification for the standards must allow for technology transfer.

TABLE 80. FEDERAL NEW SOURCE PERFORMANCE STANDARDS OF COAL LIQUEFACTION-RELATED TECHNOLOGIES (123)

New Stationary Sources Performance Standards	Pollutant	Limit of Pollutant Discharge	Opacity
Subpart Y--Coal Preparation Plants			
Thermal dryer	Particulates	0.070 g/dscm	20%
Pneumatic coal cleaning equipment		0.040 g/dscm	10%
Processing, conveying, storage, transfer, loading			20%
Subpart D--Fossil Fuel Fired Steam Generators	Particulates	0.043 kg/10^6KJ heat input derived from fossil fuel	20%
Generating more than 63 million Kcal per hr heat input (250 million Btu/hr or 264 million KJ/hr)	Sulfur dioxide	0.344 kg/10^6KJ heat input derived from liquid fossil fuel	20%
		0.516 kg/10^6KJ heat input derived from solid fossil fuel	
(When lignite or a solid fossil fuel containing 25% by wt. or more of coal refuse is burned in combination with other fuels, the standard for nitrogen oxides does not apply)	Nitrogen oxide	0.086 kg/10^6KJ heat input derived from gaseous fossil fuel	20%
		0.129 kg/10^6KJ heat input derived from liquid fossil fuel	
		0.301 kg/10^6KJ heat input derived from solid fossil fuel (except lignite)	

(continued)

TABLE 80. (continued)

New Stationary Sources Performance Standards	Pollutant	Limit of Pollutant Discharge	Opacity
Subpart E--Incinerators	Particulates	0.18 g/dscm corrected to 12% CO_2	
Subpart J--Petroleum Refineries Fluid catalytic Cracking unit Catalyst regenerator, or Incinerator-waste Heat boiler	Particulates	1.0 kg/1000 kg burn-off of coke in the catalyst regenerator	20% Proposed 25%
Catalyst regenerator	Carbon monoxide	0.050% by volume	
	Sulfur dioxide	No burning of fuel gas containing H_2S in excess of 230 mg/dscm	
Subpart K--Storage Vessels for Petroleum Liquid	Hydrocarbons		
(Storage capacity greater than 151,412 liters or 40,000 gal)	Vapor pressure = 78 to 570 mm Hg	Vessel must be equipped with floating roof, vapor recovery system or equivalent	
	Vapor pressure 570 mm Hg (11.1 psia)	Vessel must be equipped with a vapor recovery system or its equivalent	

5.2.1.1.3 Hazardous Air Pollutant Standards

National emissions standards for hazardous air pollutants are established by EPA. Standards currently exist for mercury, beryllium and asbestos. Although none of these is likely to affect SRC production, future standards for hazardous air pollutants may be applicable (116).

5.2.1.1.4 Clean Air Act

The Clean Air Act of 1970 provided EPA with the power to adopt and enforce air-pollution regulations. EPA then promulgated the National Primary and Secondary Ambient Air Quality Standards, setting the maximum ambient concentrations for various pollutants. The Clean Air Act requires that states submit an implementation plan which will specify the manner in which these standards will be achieved and maintained within each air quality control region. Such state implementation plans could have an impact on SRC commercial development by limiting industrial development in parts or all of the state.

5.2.1.1.5 Designation of Attainment and Non-attainment Areas

Every state was required to submit to the EPA by December 6, 1977, a statement of the degree of attainment of air quality in each of their Air Quality Control Regions (AQCRs) for SO_2, NO_x, CO, total suspended particulate matter (TSP), photochemical oxidants, and hydrocarbon compounds. Any AQCR (or portion thereof) shown to possess air quality superior to that promulgated in the NAAQS for SO_2 and TSP will be designated as a Prevention of Significant Deterioration (PSD) or attainment area for these pollutants. Where the air quality is shown to be worse than the NAAQS, the area will be designated as a nonattainment area (NA). Thus, any area designated to PSD status within a given state will likely experience limited industrial development (117), potentially limiting the location and development of SRC facilities.

The Clean Air Act Amendments of 1977 include comprehensive new requirements for the prevention of significant air quality deterioration in areas with air quality cleaner than minimum national standards. The requirements are to be incorporated into State Implementation Plans (SIP) under the Act after EPA has issued guidance regulations to the states (Federal Register 42(212), November 3, 1977). The states are required to complete their revisions on the SIPs by December 1, 1978.

The 1977 amendments established three classes of clean air areas and set maximum allowable increases in levels of SO_2 and TSP (above baseline*) for the Class I, Class II, and Class III areas, as shown in Table 81. Class I increments permitted only minor air quality deterioration; Class II increments permitted moderate deterioration; Class III increments permitted deterioration up to the NAAQS.

The short-term increments in all classes may be exceeded once per year at each location. The short-term concentration, thus shall be based on the second-highest measured or estimated concentration at a given site for calendar year 1974.

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*Baseline concentration means (with respect to any pollutant regulated under the Act) the ambient concentration level reflecting air quality as of January 6, 1975. For annual average concentration, this shall be based on measured or estimated concentrations for the calendar year 1974.

At present the only pollutants for which air quality increments have been established are SO_2 and particulate matter as shown in Table 81. Regulatory guidance for hydrocarbon/photochemical oxidants, carbon monoxide, and nitrogen oxides is under investigation and may proposed within two years.

TABLE 81. PSD PERMITTING AGREEMENTS (117)

	Class I	Class II	Class III	NAAQS
		(micrograms/m^3)*		
SO_2 annual	2	20	40	80
24-hour	5	91	182	365
3-hour	25	512	700	1,300**
TSP annual	5	19	37	7,560**
24-hour	10	37	75	260,150**

*All 24-hour and 3-hour values may be exceeded once per year.

**Indicates a secondary standard.

The new amendments immediately designated all the following as Class I areas:

- International parks
- National wilderness areas larger than about 2020 hectares.
- National memorial parks larger than about 2020 hectares.

- National parks larger than 2430 hectares which were in existence on the date of enactment of the Clean Air Amendments of 1977.

All areas in states which are not established as Class I (utilizing the above categories) shall be Class II areas unless redesignated. State governors may redesignate any area to Class I status. Certain areas may be redesignated to Class III status except those areas that are greater than about 4047 hectares in size, as follows:

- Existing national monuments
- Primitive areas
- Recreation areas
- Wild and scenic river areas
- Wildlife refuges
- Lakeshores and seashores
- Future national parks and wilderness areas.

Areas within Indian reservations may be redesignated only by the applicable Indian governing body.

There are 28 designated industries (shown in Table 82) that must comply with the new PSD numerical increments. However, regardless of their location, new sources must also comply with the New Source Performance Standards (NSPS), expressed as emission requirements for the designated source category. The similarity of some of these sources to synthetic

TABLE 82. MAJOR STATIONARY SOURCES SUBJECT TO PSD REVIEW

Power plants greater than 73 million W/hr

Specific sources greater than 91 Mg/yr any pollutant

Power plants

Coal cleaning plants

Kraft pulp mills

Portland cement plants

Primary zinc smelters

Iron and steel mill plants

Primary aluminum ore reduction plants

Primary copper smelters

Municipal incinerators greater than 227 Mg/day

Hydrofluoric acid plants

Sulfuric acid plants

Petroleum refineries

Lime plants

Phosphate rock processing plants

Coke oven batteries

Sulfur recovery plants

Carbon black plants (furnace process)

Primary lead smelters

Fuel conversion plants

Sintering plants

Secondary metal production facilities

Chemical process plants

Fossil-fuel boilers greater than 73 million W/hr

Petroleum storage and transfer facilities greater than 47,695 m^3

Taconite ore processing facilities

Glass fiber processing plants

Charcoal production facilities

Any other source greater than 227 Mg/yr any pollutant fuel systems suggests that NSPS are likely for SRC facilities.

5.2.1.1.6 Increment Limitations

The PSD increment limitations shown in Table 81 represent small percentages of the NAAQS concentrations for SO_2 and TSP, including allowable concentrations that exceed the level existing at the time of the first application for a permit in an area subject to PSD rules (i.e., the baseline air quality). The baseline air quality concentrations must include all projected emissions from any one of the 28 major industrial categories which began construction before January 6, 1975, but which did not go into operation by the time the baseline measurement of air quality was made (117). Emissions from any major facility on which construction began after January 6, 1975 must be counted against the maximum allowable increment limitation for any PSD area. State governors are permitted to extend exemptions in determining compliance with the allowable PSD ambient increments when the following conditions prevail:

- Ambient concentrations are increased because of fuel conversion orders.
- Increases resulting from construction or temporary emissions-related actions.
- Increases resulting from conversion from natural gas to coal as a result of low supply.
- Increases attributable to sources outside the U.S.

5.2.1.1.7 Monitoring Requirements in Nonattainment Areas (NA)

Industries presently located in nonattainment areas, even though now in compliance, will be required to impose additional future controls to bring about areal compliance. Owners contemplating the construction of new facilities in NA will be required to submit baseline air quality monitoring data. Thus, detailed advance planning will be required.

5.2.1.2 State Requirements

Ambient Air Standards and Stationary Source Performance Standards have been promulgated by individual states as well as by the federal government.

No states have as yet promulgated emission standards for coal liquefaction facilities. New Mexico has, however, promulgated such standards for coal gasification plants. Although frequently derived from federal standards, state standards may differ from federal standards by having more stringent requirements or by regulating additional pollutants. A brief summary of the environmental requirements for air pollutants in major coal bearing states is presented in the following subsections. For a more detailed summation, the reader is referred to the document, *Environmental Standards Applicable to Coal Conversion Processes* (118).

The following subsection presents a description of the highlights of the ambient air quality and emission standards for sixteen selected states, presented according to EPA region, as follows: III (Pennsylvania, West Virginia); IV (Kentucky); V, (Illinois, Indiana, Ohio); VI (New Mexico, Texas); VIII (Colorado, Montana, North Dakota, South Dakota, Utah, Wyoming); IX (Arizona), and X (Alaska). The states selected were those which had the potential for supporting a commercial SRC facility. The critical criteria were: adequate coal supply, water supply, and proximity to a market or viable distribution system. A summary of ambient air standards of these selected states is given in Tables 83 and 84.

Table 83 compares the state standards to the National Primary and Secondary Ambient Air Quality Standards, while Table 84 presents state standards for constituent categories not addressed in the National Standards. State emission standards are found in the Appendices.

5.2.1.2.1 EPA Region III (Pennsylvania and West Virginia)

Pennsylvania has adopted the National Ambient Air Quality Standards (NAAQS). Additional ambient standards apply to the following contaminants (as shown in Table 84): settled particulates (total), lead, beryllium, sulfates (as H_2SO_4), fluorides, and hydrogen sulfide). Industrial emission standards require a vapor recovery system for hydrocarbon loading equipment, and a floating roof for the hydrocarbon-water separator storage tanks. Additional emission standards for particulates and opacity are shown in the Appendices.

The ambient air quality standards of West Virgnia are identical to the six regular criteria pollutants of the NAAQS. Regulations for coal preparation, drying and handling, and manufacturing process regulations are shown in the Appendix F.

TABLE 83. NATIONAL PRIMARY AND SECONDARY AMBIENT AIR QUALITY STANDARDS COMPARED TO STATE STANDARDS[a,b]

Constituent	Concentration (micrograms/m³)	Remarks	EPA REGIONS REPRESENTED BY SELECTED STATES III		IV		V		VI				VIII				IX	X
			PA	WV	KY	IL	IN	OH	NM	TX	CO	MT	ND	SD	UT	WY	AZ	AK
Sulfur oxides primary	80	AAM[c]	*	*	*	*	*[e]	60[e]	52	*	60[e]	52[e]	60[e]	60	*	60	50[c,e]	*
	365	24 hr max[d]	*	*	*	*	*[e]	260[e]	262	*	260[e]		260[e]	260	*	260	260[c,e]	*
secondary	1300	3 hr max[d]	*	*	*	*	f	—		*	*[c,e]				*	*	*[e]	+
Particulates primary	75	AGM[c]	*	*	*	*	*	--	60	f	45AAM	*	--	--	*	--	--	-
	260	24 hr max[d]	*	*	*	*	*	--	150[f]	f	150	200[g]	--	--	*	--	--	-
secondary	60	AGM[c]	*	*	*	*	*	+		f			+	+	*	+	+	+
	150	24 hr max[d]	*	*	*	*	*	+		f			+	+	*	+	+	+
Carbon monoxide primary	10,000	8 hr max[d]	*	*	*	*	*	*	9	*		*	*	*	*	*	*	*
secondary	40,000	1 hr max[d]	*	*	*	*	*	--	13	*		*	*	15	*	*	*	*
Photochemical oxidants primary & secondary	160	1 hr max[d]	*	*	*	*	*	119[f]	119	*		*	*	125	*	*	*	*
Nonmethane hydrocarbons primary & secondary	160	3 hr max[d]	*	*	*	*	*	126[f]	126	*		*	*	125	*	*	*	*
Nitrogen dioxide primary & secondary	100	AAM[c]	*	*	*	*	*	*	94[f]	*		*	*[f]	*[f]	*	*	*	*

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[a] This table compares only those state standards that cover the same constituents and sampling time period as the National Standards. If a constituent regulated by the National Standards has no comparable state standard, the National Standard is considered to be in effect for that contaminant. State standards covering additional contaminant categories are found in the Appendices.

[b] Reference conditions for National and most state standards are as follows: Temperature = 25°C, Pressure = 760 mmHg. State having exceptions to these conditions are: Ohio - 21°C; South Dakota - 20°C; Wyoming - 21°C.

[c] AAM - annual arithmetic mean; AGM - annual geometric mean.

[d] Maximum value not to be exceeded more than once per year.

[e] Sulfur dioxide standard.

[f] Several standards as listed under this category. See Appendices.

[g] Not to be exceeded more than 1% of days/year.
* - State standard same as the National Standard.
+ - State has adopted this National Secondary Standard as a primary standard.
- - No standard exists.

TABLE 84. SUMMARY OF STATE AMBIENT AIR QUALITY STANDARDS FOR WHICH NO NATIONAL STANDARD EXISTS

		EPA Regions Represented by Selected Coal-Bearing States										
		III	IV	V		VI		VIII				X
Constituent	Remarks	PA	KY	IN	OH	NM	TX	MT	ND	SD	WY	AK
Photochemical oxidants ($\mu g/m^3$)	4 hr max[a]				79							
	24 hr max*				40							
Nonmethane hydrocarbons ($\mu g/m^3$)	24 hr max*				331							
Nitrogen dioxide	1 hr max[b]					188(NO_2)			200	250		
Nitrogen oxides ($\mu g/m^3$)	24 hr max*								715			
Sulfur dioxide ($\mu g/m^3$)	AAM			60[d]				262[c]				
	1 hr max			1100[d]				655[p]				
	24 hr ave.			260[d]								
Hydrogen sulfide ($\mu g/m^3$)	1 hr max*	139	14			0.003ppm						50
	1/2 hr max						111[3]	42[f]	45[f]		40	
	1/2 hr max						167	70[g]	75[g]		70	
	24 hr max	7										
Reduced sulfur compounds ($\mu g/m^3$)	20 min max					0.003ppm						
Reactive sulfur (mg of SO_3/100 cm^2/day)	AAM							0.25	0.25			
	1 mo. max.							0.50	0.50			
Suspended sulfate ($\mu g/m^3$)	AAm							4				
	24 hr max							12[h]	12[h]			
Sulfates ($\mu g/m^3$)	24 hr max	3										
	30 day max	1										
Sulfuric acid mist ($\mu g/m^3$)	AAM						15					
	24 hr max						50[i]					
	1 hr max						100					
	max allowed											
Particulates ($\mu g/m^3$)	5 hr max						100					
	3 hr max						200					
	1 hr max						400					
Particulates (COH/1000 LM)[j]	24 hr max*		19.7			1.3						
primary	AGM		1.3AAM					1.3	1.3			
secondary	3 mo max*		1.6									
Settled particulates (mg/km^2/mo) (dustfall)	AAM	8										
	30 day max	15										
	3 mo ave[k]			5.3			5.3	5.3			5[m]	
	3 mo ave[l]						10.5	10.5			10[n]	
Suspended particulates ($\mu g/m^3$)[h] H_2 (ppm)	24 hr max	0.005										
	1 hr max	0.1										
Gaseous fluoride-HF (ug/m^3) primary	1 mo max		0.8			0.8	0.3[o]				0.3[o]	
	1 week max		1.6			1.6						
	1 day max		2.9			2.9						
	12 hr max		3.7			3.7						
Total fluorides (as HF) primary ($\mu g/m^3$)	24 hr ave	5	0.8				0.8				0.8	
	12 mo ave		40			40	35				25	
	6 mo ave											
Fluorides (as F)[q] ppm dry wt. basis)	3 mo ave		60			60						
	2 mo ave		80			80						
	1 mo ave											
Heavy metals ($\mu g/m^3$)	30 day ave	5				10	5		15			
Lead ($\mu g/m^3$)	30 day max	0.01				0.01	0.01					
Beryllium ($\mu g/m^3$)	30 day ave					0.01						
	24 hr ave											
Asbestos ($\mu g/m^3$)	30 day ave					0.01						

FOOTNOTES TO TABLE 84

* Not to be exceeded more than once per year

[a] Not to be exceeded more than one consecutive four hour period per year.

[b] Not to be exceeded more than one percent of the time in any three month period.

[c] Not to be exceeded over one percent of the days in any three month period.

[d] Secondary standard.

[e] Applicable only when residential, business or commercial areas are downwind of the source of emissions.

[f] Not to be exceeded more than twice in any five consecutive days.

[g] Not to be exceeded more than twice per year.

[h] Not to be exceeded over one percent of the time.

[i] Not to be exceeded more than once per 24 hour period.

[j] Coefficient of haze per 1000 linear meters.

[k] Residential areas.

[l] Industrial areas.

[m] Value for any 30 day period in residential areas, including 1.7 Mg/km^2/month background settled particulates.

[n] Same as above, but for industrial areas.

[o] Micrograms per square centimeter per 28 days.

[p] Not to be exceeded more than one hour in any four consecutive days.

[q] In and on forage for animal consumption.

5.2.1.2.2 EPA Region IV (Kentucky and Ohio)

The state of Kentucky air quality standards are similar to the NAAQS, except that standards were included for hydrogen sulfide (14 micrograms/m^3 one hour maximum), gaseous hydrogen fluoride (2.86 micrograms g/m^3, 24-hour maximum), and total primary fluorides of 80 ppm (30 day average). Kentucky also has issued standards of performance for petroleum refineries for particulates, carbon monoxide, and sulfur dioxide.

The ambient air quality standards of Ohio are shown in Tables 83 and 84. Ohio emissions standards for the storage of hydrocarbons are comparable to those in other coal-producing states. Carbon monoxide emissions from the petroleum refinery processes must pass through an afterburner prior to discharge, while photochemical oxidants must be incinerated to a maximum of 90 percent oxidation prior to discharge to the atmosphere. Industrial process emission standards promulgated for particulates, SO_x, NO_x, hydrocarbons, CO, and photochemical oxidants may be applicable to coal conversion technologies. Ohio has established air quality priority zones; these presently do not meet EPA standards for SO_x, NO_x, and particulates. The SO_x emission limit is a mathematical function of the total emission discharge, while the limit of particulate emissions is a function of the process throughput.

5.2.1.2.3 EPA Region V (Illinois, Indiana and Ohio)

Illinois has promulgated both air quality standards and emission standards and limitations for stationary sources. The Illinois air quality standards are the same as the NAAQS standards. The Illinois performance standards for stationary sources are shown in the Appendices. The Illinois stationary source standards not only address the six regular criteria pollutants of the NAAQS, but also visible emission standards and sulfuric acid mist. Also addressed are organic mineral storage, loading, organic material, water separation, pumps and compressors, other discharges of organic material to the atmosphere, waste gas disposal, vapor blowdown, and the clean-up and disposal of organic materials. These standards are considered to be among the most comprehensive in the coal-producting states.

Indiana ambient standards differ from the NAAQS only in having categories for sulfur dioxide and settled particulates. In addition, Indiana has laws controlling the storage and handling of volatile hydrocarbon liquids. A vapor recovery system, floating roof or alternative system which meets approval of the proper state agencies is required. Volatile organic liquid-water separators require either a solid cover or one of the vapor control methods required for storage systems, essentially analogous to the Illinois standards.

5.2.1.2.3 EPA Region VI (New Mexico and Texas)

New Mexico is presently the only state that has promulgated emission standards applicable to coal conversion facilities, specifically coal gasification plants. Stacks at least ten diameters tall and equipped with enough sampling ports and platforms to perform accurate sampling are required. Particulate emissions requirements exist for briquet forming areas, coal preparation areas, and the gasification plant itself - with an additional requirement for gas burning boilers. Limits have been placed on dischargeable concentrations of sulfur, hydrocarbons, ammonia, hydrogen chloride, hydrogen cyanide, hydrogen sulfide, carbon disulfide, and carbon oxysulfide as well. These limits are compiled in the Appendices, entitled "New Mexico Emission Standards for Commercial Gasifiers," and are stringent compared with the other coal-producing states. However, a review of New Mexico air laws pertaining to petroleum refineries reflects an interest in environmental preservation, not a distrust of new technology. Emission standards for ammonia and hydrogen sulfide, for example, are the same for both industries. In fact, refineries have additional limits on mercaptan and carbon monoxide not presently included in gasification legislation. These requirements were presented previously in Table 80. The ambient air criteria for heavy metals and the difference in dischargeable carbon monoxide concentrations between new and existing refineries are worthy of note. The ambient air quality standards of New Mexico include a heavy metals standards of 10 $\mu g/m^3$, and a 0.01 $\mu g/m^3$ standard for beryllium. The New Mexico standards for the 24-hour maximum for particulates and sulfur dioxide are somewhat lower than those for the NAAQS; all others are very similar.

The ambient air quality standards of Texas are identical to the NAAQS for all six of the regular criteria pollutants. Texas has imposed additional ambient standards for hydrogen fluoride gas, net ground-level concentrations for emissions of H_2S, sulfuric acid and particulates, as shown previously in Table 84. Emission limits for fossil fuel steam generators were also issued for SO_x, NO_x and particulates. The emission rates for SO_x and particulates are both functions of the effective stack height. Visibility requirements prohibit exceeding 20 percent opacity; these limits apply to 5-minute periods and do not include opacity resulting from uncombined water mists.

5.2.1.2.4 EPA Region VIII (Colorado, Montana, North Dakota, South Dakota, Utah and Wyoming)

Colorado has promulgated ambient standards for sulfur dioxide and particulates. Of the standards of performance enacted for stationary sources, those applicable to petroleum refineries are probably most indicative of future legislation relevant to the SRC technology. These standards are reviewed in the Appendices. Other relevant Colorado legislation pertains to oil-water separators similar to those used in SRC pilot plants. One or more of the following vapor loss controls is required: a solid cover, a floating roof, a vapor recovery system, or special equipment which can demonstrate equal or superior efficiency.

Montana ambient standards differ from the NAAQS in specifying sulfur dioxide standards, and in all the particulate standards except the annual geometric mean. In addition, Montana has promulgated standards for H_2S, fluorides, settled particulates, lead, reactive sulfur (SO_3), suspended sulfate sulfuric acid mist, lead, and beryllium, as shown previously in Table 84.

The ambient air quality standards of North Dakota have been established in accordance with the state air quality guidelines which call for preservation of the health of the general public, plant and animal life, air visibility and natural scenery. The guidelines also require that ambient air properties shall not change in any way which will increase corrosion rates of metals or deterioration rates of fabrics. Additionally, emissions restrictions from industrial processes exist for particulates and sulfur oxides. For particulates, North Dakota requires the use of the Arizona equation governing process industries in that state. Sulfur dioxide emissions are limited to 1.3 μg/J heat input from coal.

The ambient air quality standards of South Dakota are similar to, but slightly more stringent than the NAAQS. South Dakota has reserved the right to set emissions standards for any source which may be exceeding the ambient standards. Standards for fuel burning installations and general process industries are listed in the Appendices.

The state of Utah has no ambient or new source standards at this time. Current federal standards are, therefore, applicable. The Utah Air Conservation Regulations note that the Utah Air Conservation Committee and the State Board of Health do not agree with most of the federal standards, but there is no indication of the types of standards these organizations favor. State emissions standards have been set for particulates requiring 85 percent control. Sulfur emissions must meet federal ambient and new source standards.

Four of the six regular criteria pollutants of the Wyoming ambient air quality criteria (CO, hydrocarbons, NO_x and photochemical oxidants) are identical to the NAAQS, as shown in Table 83. The Wyoming emission standards, shown in the Appendices are largely applicable to fossil fuel burning sources. Additional requirements have been issued governing hydrocarbon storage and handling. Waste disposal combustion systems for vapor blowdown or emergency situations are to be burned in smokeless flares. Pressurized tanks, floating roofs, or vapor recovery systems are required for the storage of hydrocarbons.

5.2.1.2.5 EPA Region IX (Arizona)

The ambient air quality standards for Arizona for particulates correspond to the NAAQS secondary standard of 60 $\mu g/m^3$ (AGM) and 150 $\mu g/m^3$ (24-hour maximum). The only other variance in Arizona versus the NAAQS standards is the annual maximum value for sulfur oxides (50 versus 80 $\mu g/m^3$) and the 24-hour maximum (260 versus 365 $\mu g/m^3$). The Arizona air quality goals and industrial emission standards are given the Appendices.

5.2.1.2.6 EPA Region X (Alaska)

The ambient air quality standards of Alaska are consistent with the NAAQS, except for the particulates-primary standard (annual geometric mean of 60 compared to 75 micrograms/m^3), the lack of a standard for hydrocarbons, and the addition of a 30 minute maximum standard for reduced sulfur compounds of 50 $\mu g/m^3$. Emission standards for fuel-burning equipment and industrial processes in Alaska are shown in the Appendices.

5.2.2 Comparisons of Waste Streams With Emission Standards

Potential point source emissions to the atmosphere from each of the six basic unit operations of the conceptualized SRC-II system are diagrammed in Figure 63. Available characterization data are presented in Section 3.0. Also displayed are emissions from auxiliary processes, which are categorized in terms of:

- Those that are clearly required for realization of the primary functions of the system, in the center of the diagram

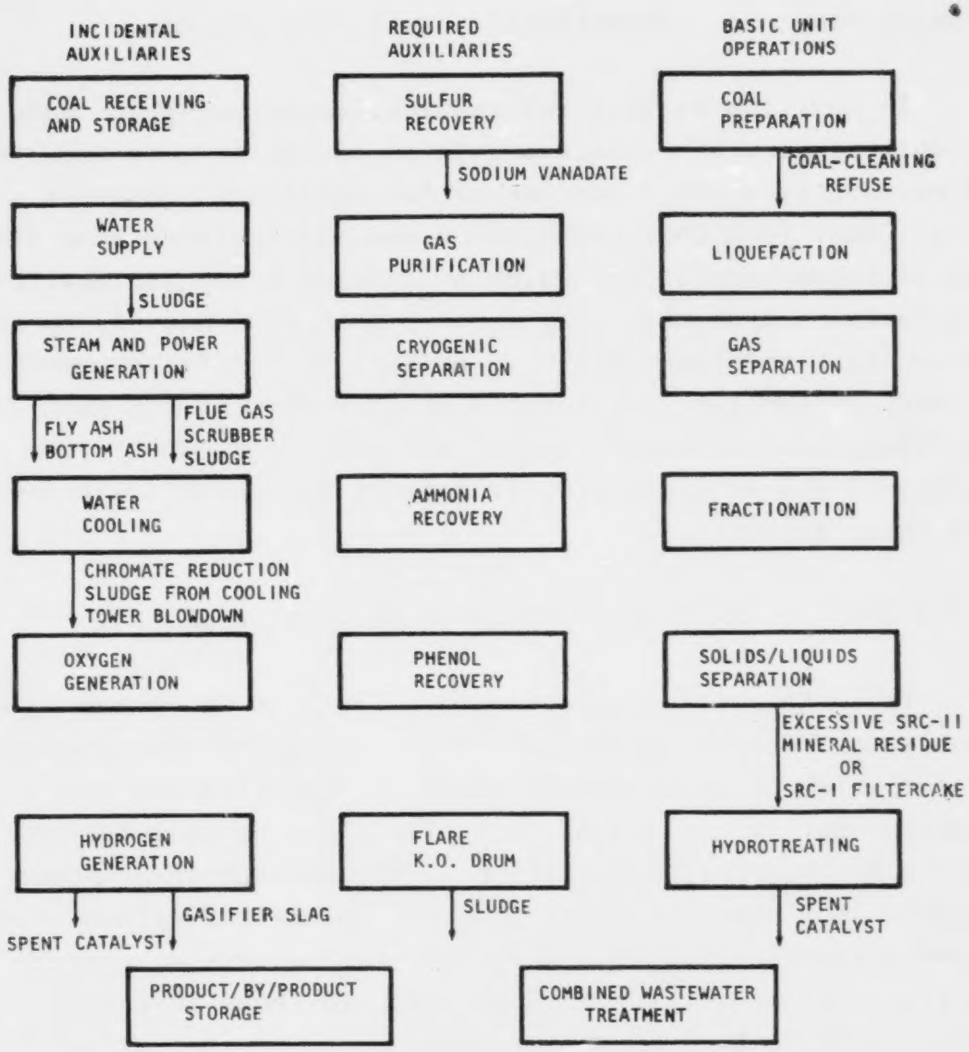
INCIDENTAL AUXILIARIES
REQUIRED AUXILIARIES
BASIC UNIT OPERATIONS
COAL RECEIVING AND STORAGE
SULFUR RECOVERY
COAL PREPARATION
SODIUM VANADATE
COAL-CLEANING REFUSE
WATER SUPPLY
GAS PURIFICATION
LIQUEFACTION
SLUDGE
STEAM AND POWER GENERATION
CRYOGENIC SEPARATION
GAS SEPARATION
FLY ASH BOTTOM ASH
FLUE GAS SCRUBBER SLUDGE
WATER COOLING
AMMONIA RECOVERY
FRACTIONATION
CHROMATE REDUCTION SLUDGE FROM COOLING TOWER BLOWDOWN
OXYGEN GENERATION
PHENOL RECOVERY
SOLIDS/LIQUIDS SEPARATION
EXCESSIVE SRC-II MINERAL RESIDUE OR SRC-I FILTERCAKE
HYDROGEN GENERATION
FLARE K.O. DRUM
HYDROTREATING
SPENT CATALYST
GASIFIER SLAG
SLUDGE
SPENT CATALYST
PRODUCT/BY/PRODUCT STORAGE
COMBINED WASTEWATER TREATMENT

Figure 63. Potential emissions from SRC-II basic unit operations and auxiliary processes

- Those that are incidental to the primary functions of the SRC system, per se (left side).

The auxiliary processes are so divided to allow a clearer perception of those emissions that are most closely identified with the system, as against those that are considered common to conventional fossil fuel systems.

In addition to this information, comparisons are made in this section of certain regulated air pollutants reported to emanate from waste streams of two auxiliary processes (i.e., dust from coal preparation and particulates from flue gas of steam generation) which may exceed known air quality standards, and/or which may present potential hazards to the environment and human health. In Section 5.2.3 the impacts of certain inorganic pollutants associated with the two auxiliary process waste streams are discussed, while in Section 5.2.4 an evaluation is made of unregulated pollutants and their effects.

5.2.2.3 MATEs for Regulated Air Pollutants

Table 85 lists regulated air pollutants which may be a problem. Those pollutants which do not exceed the standards or for which no environmental harm is predicted are not listed. Determinations of potential environmental hazard were made, based on application of MEG and SAM/IA methodologies. For some pollutant species, documented evidence was found suggesting possible environmental hazards at concentrations below existing MATE values. In those instances proposed MATEs have been developed, based on evaluation of the documented evidence. Responsibility for official revision of all MATE's rests with the U.S. EPA. The

TABLE 85. REGULATED AIR POLLUTANTS WHICH MAY EXCEED UNKNOWN STANDARDS AND/OR MAY CAUSE HEALTH OR ENVIRONMENTAL HAZARD

Pollutant	Projected Air Concentration ($\mu g/m^3$) Due to Dust from Coal Preparation Module		Due to Boiler Flue Gas		Health-Based MATE ($\mu g/m^3$)	Standard ($\mu g/m^3$)	Comments
	Average U.S. Coal	Maximum U.S. Coal	Average	Maximum			
Arsenic	0.010-7.3	0.052-23.	6.0	19	2.0	OSHA standard:500	The trivalent state of arsenic is most toxic. NIOSH recommends that no worker be exposed to 2 μg As/m^3 or more (43).
Barium	0.22-167.	0.45-330.	130.	250.	500	OSHA standard:500	BaO and $BaCO_3$ have caused respiratory injury in man. Barium stimulates all muscle types, causes vasoconstriction, and initially stimulates and then paralyzes the central nervous system. Barium is readily excreted, and probably non-cumulative.
Beryllium	0.0013-0.94	0.0027-2.0	0.55	1.2	2.0	OSHA standard: 2. National Emission standard for hazardous air pollutants: 0.01 $\mu g/m^3$, 30-day average	Beryllium is toxic through all routes of absorption, but the major hazard to health is via inhalation. Berylliosis, a severe health disease develops from chronic exposure to soluble as well as insoluble compounds as particulates in air. Apparently, the particle size of the beryllium dust is a critical factor with regard to its potential for causing berylliosis. The lowest toxic concentration reported for humans in 100 $\mu g/m^3$. The lowest dose producing a carcinogenic response is 1.8 g Be/m^3 inhaled by a monkey for 24 hrs. NIOSH recommends that occupational exposure to beryllium and its compounds not exceed 2 $\mu g/m^3$ as a time weighted average for an 8-hour workday. A ceiling of 25 $\mu g/m^3$ is recommended. The TLV is 2 $\mu g/m^3$. Beryllium is classified by ACGHI as an "Occupational Substance Suspect of Oncogenic Potential for Workers," based on limited epidemological evidence and demonstration of being or malignant growths in test animals.
Cadmium	0.0013-2.3	0.015-11.	3.6	17.	10.*	OSHA standard:100	In the range of 0.000 to 0.062 $\mu g/m^3$ there appears to be a significant correlation (r = 0.76 with 26 degrees of freedom or p less than 0.0001; i.e., less than 1 chance in 10,000 that the observed correlation is due solely to chance) between the cadmium concentration and diseases of the heart. In view of these data, the Illinois Institute for Environmental Quality recommends a 24-hour average cadmium level of 0.05 $\mu g/m^3$. If possible, discharge of cadmium into the atmosphere should not be tolerated (43, 47).
Carbon monoxide			$5.1x10^4$	$5.1x10^4$	$4.0x10^4$	National Primary and Secondary Air Quality Std: 1.0 x 10^4 (8 hr) OSHA standard: $5.5x10^4$	Carbon monoxide asphyxiates. It has an affinity for hemoglobin 200-250 x that of oxygen (43).

(continued)

TABLE 85. (continued)

Pollutant	Projected Air Concentration ($\mu g/m^3$) Due to Dust from Coal Preparation Module Average U.S. Coal	Maximum U.S. Coal	Due to Boiler Flue Gas Average	Maximum	Health-Based MATE ($\mu g/m^3$)	Standard ($\mu g/m^3$)	Comments
Chromium	0.015-11.	0.035-26.	7.3	18.	1.0	OSHA standard:500 ug/m^3 (soluble)	The NIOSH recommendation for occupational exposure, considering the potential carcinogenity of Cr (IV) is ug/m^3 (43).
Copper	0.011-8.5	0.030-23	5.1	14.	200.	OSHA standard: Dust: 1000. Fume: 10.	Exposure to copper may cause irritation to the gastrointestinal tract, anemia, respiratory irritation, and eye and skin irritations. Damage to the liver, kidneys, and nervous system may result from exposure to copper (43).
Fluorides	0.070-52.	0.14-110.	ca.8.6	ca.14.	2500.*	OSHA standard:2500	Fluorine at levels greater than 2000 $\mu g/m^3$ acts as direct cellular poison by interfering with calcium metabolism and enzyme mechanisms. Nosebleed, cough, other irritation of the respiratory tract and of the eye are usually associated with 8-hour exposures greater than 2500 $\mu g/m^3$ although several studies suggest some of these effects can occur down to 240 $\mu g/m^3$. The results of studies of aluminum plants in the United States, Scotland, and the USSR are given in Ref. 47. Levels of 0.5 μg atmospheric fluorine/m^3 for 10 days is toxic to conifer needles. Atmospheric fluorine levels of 1.8 $\mu g/m^3$ is toxic to English elm, blueberry and apple. Airborne fluorides are injurious to corn, sorghum, tomatoe, soybeans, gladiolus and a variety of other plants. A level of 25 $\mu g/m^3$ for emissions should prevent the adverse health effects to persons living near the facility; however, the effect of this level on cash crops at some distance from the facility cannot be determined at this time and will probably have to be determined on a site specific basis.
Iron	13.-9900.	30-22000.	3700.	8200.	1000.	OSHA Standard 10000 $\mu g/m^3$ iron-oxide fume	1976 ACGIH TLV is 5000 $\mu g/m^3$ (43).
Lead	0.012-8.7	0.058-43.	6.5	32.	150.*	OSHA standard: 200 $\mu g/m^3$	At ambient air concentrations of 100 $\mu g/m^3$, subclinical effects of lead poisoning, including mild nonspecific symptoms including fatique, dizziness, anorexia and basophilic stripping. At 1 $\mu g/m^3$, airborne lead produces altered metabolic effects. The Illinois Institute for Environmental Quality recommends a maximum level of 1.5 $\mu g/m^3$ based on a 24-hour average sample. Adjusting this for an 8-hour/day exposure roughly gives 4.5 ug/m^3 for 8 hours and none for the next 16 hours. The 1976 AGCIH TLV is 150 $\mu g/m^3$.

(continued)

TABLE 85. (continued)

	Projected Air Concentration ($\mu g/m^3$)						
	Due to Dust from Coal Preparation Module		Due to Boiler Flue Gas				
Pollutant	Average U.S. Coal	Maximum U.S. Coal	Average	Maximum	Health-Based MATE ($\mu g/m^3$)	Standard ($\mu g/m^3$)	Comments
Manganese	0.032-24.	0.12-92.	13.	48.	5000.*	OSHA standard: 5000 $\mu g/m^3$	At levels greater than 0.006 $\mu g/m^3$ manganese oxides significantly increase the catalytic conversion of sulfur dioxide to sulfur trioxide which, in the presence of moisture, results in the formation of sulfuric acid and airborne sulfates. Manganese levels as low as 500 $\mu g/m^3$ can lead to emotional instability, apathy, hallucinations, compulsory acts, muscular hypertonia, muscular fatigue, and sexual depression. Levels as low as 20 $\mu g/m^3$ can lead to tremors, facial masking, and reduced blinking. Levels of of 100 $\mu g/m^3$ can lead progressive weakness. It is well to note in this regard that occupational exposures are usually on a 40-hour, 5-day per week basis, where off-work hours and weedends constitute recovery time from the health effect of hazardous materials (43,47).
Nickel	0.017-13	0.11-81.	6.6	42.	15.	OSHA standard: 1000.	1976 ACGIH TLV is 100 $\mu g/m^3$. Workers exposed to nickel may develop a sensitivity to nickel and dermatitis. Nickel absorbed through inhalation may be associated with nasal, and lung cancer (Cleland and Kingsbury, 78). The new NIOSH recommendation for occupational exposure to nickel is 15 $\mu g/m^3$. The value was lowered due to evidence of nasal and lung cancer resulting from nickel exposure (43).
Nitrogen oxides			$8.5x10^5$	$8.5x10^5$	9000.*	0.45 lb/mm Btu input (Federal Standard) = 0.19 μg/joule input or ca. 120-200 mg/day	Nitrogen dioxide at levels greater than 5 ppm in injested material or 9000 $\mu g/m^3$ caused corrosion as well as irritation of skin, eyes, digestive tract, or lungs and decreased pulmonary function. At concentrations of less than 1880 $\mu g/m^3$ nitrogen dioxide caused reduced resistance to infection and emphysema and alveolar extension in mice after one year exposure. Other pathological effects were noted in lungs of laboratory animals exposed to nitrogen oxide levels ranging from ca.1100 to 9000 $\mu g/m^3$. These pathological effects included hyperplasia, bacterial dysfunction, decreased compliance and increased lung weight, hypertrophy of bronchial epithelium, increased breathing rate sustained, reduced resistance to infection. There is some evidence to show that prolonged exposure to NO_2 levels of 117 to 205 $\mu g/m^3$ can contribute to increased prevalence of chronic bronchitis, increased incidence of acute lower respiratory disease and diminished pulmonary function in school children. Nitrogen dioxide has been associated with fabric fading.

(continued)

TABLE 85. (continued)

Pollutant	Projected Air Concentration ($\mu g/m^3$) Due to Dust from Coal Preparation Module Average U.S. Coal	Maximum U.S. Coal	Due to Boiler Flue Gas Average	Maximum	Health-Based MATE ($\mu g/m^3$)	Standard ($\mu g/m^3$)	Comments
							fading. Nitrogen dioxide at levels of 940 $\mu g/m^3$ for 10-12 days suppressed the growth of pinto beans and tomatoes. Navel orange yield is greatly reduced at 470 $\mu g/m^3$ for 240 days or by 470-940 $\mu g/m^3$ for 35 days. An evaluation of all available information leads to the conclusion that an average annual exposure to 150 $\mu g/m^3$ or repeated two-to-three hour exposures to 280 $\mu g/m^3$ or about 36 days of the year can be associated with an increased susceptibility to respiratory infection in children (43,47).
Particulates	11-68.x10^4	1.1-68.x10^4	3.7x10^6	3.7x10^6	Not available	OSHA standard: 1.5x10^4 NSPS:4.0x10^4 Ambient Air Quality standard: 0.075	Although the size range given for atmospheric particulates extends from about 0.005 to 500 microns, the particulates from coal combustion appear in a more limited size range. These products tend to be found in the 0.01 to 10 micron range. Because this range neatly brackets the size defined for respirable particulates, the coal combustion particulates pose a significant potential for adverse human health effects (153). The lungs constitute the major route of entry for toxic airborne particulates. The probability of of particle deposition and the anatomical position of the respiratory system in which deposition occurs is primarily a function of particle size. Those less than about .01 micron in diameter tend to behave like gases, and are generally not deposited in the aleveolar or pulmonary region, while larger particles show a greater tendency to deposit in the nasopharngeal and tracheobronchial regions. The main effects of particulates on plant is most likely due to the reduction in light intensity, especially in winter. The formation of sooty deposits on leaves also reduce the rate of assimilation of carbon dioxide. Particulates apparently block the assimilation organs (stomata) of farm crops; the effect is enhanced in forest trees because the pores become progressively blocked with age. In fir needles that have been heavily dusted with fly ash, gas exchange was found to be inhibited by clogging 90 percent of the stomata; agricultural productivity was decreased by as much as 80 percent from sulfur dioxide plus fly ash pollution from a coal-fired power plant lacking filters (109).

(continued)

TABLE 85. (continued)

	Projected Air Concentration ($\mu g/m^3$)						
	Due to Dust from Coal Preparation Module		Due to Boiler Flue Gas				
Pollutant	Average U.S. Coal	Maximum U.S. Coal	Average	Maximum	Health-Based MATE ($\mu g/m^3$)	Standard ($\mu g/m^3$)	Comments
Sulfur suspended sulfates	20-15000.	32-24000.					The exact form of the sulfur is unknown; the form likely will be suspended sulfate, hydrogen or sulfide or sulfur dioxide are discussed below: The MATEs are not available for suspended sulfates. Best judgment estimates based on preliminary studies of 24-hour mean threshold levels for aggravation of cardiopulmonary symptoms in the elderly as well as increased aggravation of asthia at 8-10 $\mu g/m^3$ of suspended sulfates. Ventilatory function in children exposed to suspended sulfate concentrations of about 8.3 $\mu g/m^3$. It was the author's best judgement that eight or nine years of exposure to about 10 to 13 $\mu g/m^3$ of suspended sulfates might reduce ventilatory function. If these suspended sulfate exposures were accompanied by exposure to about 200 to 250 $\mu g/m^3$ of sulfur dioxide and about 100 to 150 $\mu g/m^3$ of total suspended particulates, further reductions in ventilatory function might be expected. Best judgement estimates of the threshold level for increase in acute lower respiratory tract infections in children was 3 years of exposure to 15 $\mu g/m^3$ (112).
sulfur dioxide					13000.*	National Parimary and Secondary Ambient Air Quality Standard: 80. New Stationary Source Performance Standard: 1.2 lb/10^6 Btu = _ca_.0.5 ug/joule input or _ca_.320-530 mg/day	Significant metal corrosion especially of zinc and steel may occur at sulfur dioxide concentrations above 20 $\mu g/m^3$. Concentrations above this level also may adversely affect paper and leather products. An increase in lung cancer mortality has been associated with long term mean sulfur dioxide levels of 115 $\mu g/m^3$ when compared to levels of 75 $\mu g/m^3$. Studies in New York and London have shown an increase in mortality at SO_2 levels above 130 $\mu g/m^3$. Levels of 95 $\mu g/m^3$ have been associated with aggravation of symptoms in the elderly, aggravation of asthma, decreased lung function in children, increased acute lower respiratory disease in families, increased prevalance of chronic bronchitis, increased acute respiratory disease in families and increased hospital admission with respiratory illness. A best estimate of a maximum safe level is 95 $\mu g/m^3$ (112,140).

(continued)

TABLE 85. (continued)

Pollutant	Projected Air Concentration ($\mu g/m^3$)				Health-Based MATE ($\mu g/m^3$)	Standard ($\mu g/m^3$)	Comments
	Due to Dust from Coal Preparation Module		Due to Boiler Flue Gas				
	Average U.S. Coal	Maximum U.S. Coal	Average	Maximum			
Hydrogen sulfide					15000.*	OSHA standard: 20865. NSPS: 6955.	Levels of hydrogen sulfide from 450 to 1000 $\mu g/m^3$ have been associated with pathological syndromes including increased incidence of decreased corneal reflex (conveyance and divergence), nausea, insomnia, shortness of breath and headaches following chronic exposure. Levels of only 120 $\mu g/m^3$ are associated with increased incidence of metal depression, dizziness, and blurred vision. In infants, chronic hydrogen sulfide exposures to levels of 100-1000 $\mu g/m^3$ have produced a syndrome usually manifested as undernourishment, delayed growth, general weakness and retarded physical and neurophysical development. Obviously, a MATE of 100 $\mu g/m^3$ would be more appropriate for this (43,112).

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*For reasons listed under "Comments" this MATE appears too high.

regulated air pollutants, for which reevaluation of existing MATE values by US EPA is recommended, are shown in Table 86.

TABLE 86. SUGGESTIONS FOR MORE STRINGENT MATES FOR REGULATED AIR POLLUTANTS

Substance	Present Health-Based MATE ($\mu g/m^3$)	Proposed Health-Based MATE ($\mu g/m^3$)
Cadmium	10	0.05
Fluoride	2500	25
Lead	150	1.5
Manganese	5000	20
Nitrogen oxides	9000	110
Sulfur dioxide	13000	110
Hydrogen sulfide	15000	120
Particulates	Not available	1.5×10^4

5.2.3 Impacts on Ambient Air Quality

The SAM/IA analysis (potential degree of hazard) for atmospheric waste streams is given in Tables 87 and 88. The SAM/IA analysis indicates that on the average, aluminum, arsenic, chromium, iron, lithium, and silicon may represent an environmental or health hazard in the airborne coal dust which escapes the control devices from coal preparation. Carbon monoxide, ammonia, and carbon dioxide may represent an environmental hazard in the emission after treatment of the Stretford tail gas. No substances are emitted in toxic quantities from the oxygen generation plant. Environmentally hazardous quantities of carbon dioxide and carbon monoxide may be emitted from the flare. Arsenic, chromium, iron, sulfur dioxide, nitrogen oxides, and carbon monoxide may be present in environmentally significant concentrations in the boiler flue gas.

TABLE 87. SAM/IA ANALYSIS OF ATMOSPHERIC EMISSIONS OF COAL PRETREATMENT AND FLY ASH FROM STEAM GENERATION

	Potential Degree of Hazard (Health Based MATE)					
	Dust from Coal Preparation				Fly Ash from Steam Generation	
	"Average U.S. Coal"		"Maximum U.S. Coal"			
Element	Min.	Max.	Min.	Max.	"Average U.S. Coal"	"Maximum U.S. Coal"
Aluminum	0.0023	1.7*	0.0032	2.4*	0.76	1.05*
Antimony	4.0x10^{-6}	0.029	9.0x10^{-6}	0.0063	0.0015	0.0064
Arsenic	0.0049	3.6*	0.016	12*	3.0*	9.7*
Barium	4.5x10^{-4}	0.33	9.0x10^{-4}	0.67	0.26	0.50
Beryllium	6.3x10^{-4}	0.47	0.0014	1.0*	0.28	0.60
Boron	1.6x10^{-5}	0.012	3.5x10^{-5}	0.026	0.047	0.10
Cadmium	3.1x10^{-4}	0.23	0.0015	1.1*	0.36	1.7*
Calcium	4.3x10^{-4}	0.32	9.6x10^{-4}	0.71	0.098	0.22
Carbon monoxide					1.3*	1.3*
Cerium	4.4x10^{-7}	3.3x10^{-4}	6.1x10^{-7}	4.5x10^{-4}		
Cesium	1.3x10^{-8}	9.8x10^{-6}	2.2x10^{-8}	1.6x10^{-5}	8.8x10^{-6}	1.5x10^{-5}
Chromium	0.015	11*	0.035	26*	7.3*	18*
Cobalt	1.8x10^{-4}	0.14	4.5x10^{-4}	0.33	0.10	0.25
Copper	5.7x10^{-5}	0.42	1.5x10^{-4}	0.11	0.025	0.069
Dysprosium	1.2x10^{-7}	9.3x10^{-5}	2.2x10^{-7}	1.7x10^{-4}		
Fluorine	2.8x10^{-5}	0.021	5.8x10^{-5}	0.043	_ca_.0.00027	_ca_.0.0055
Gallium	7.9x10^{-7}	5.9x10^{-4}	1.3x10^{-6}	9.3x10^{-4}	2.4x10^{-4}	3.7x10^{-4}
Germanium	1.0x10^{-5}	0.0074	2.2x10^{-5}	0.017	0.0044	0.0099
Hafnium	1.5x10^{-6}	0.0011	2.2x10^{-6}	0.0016	6.5x10^{-4}	9.4x10^{-4}
Hydrocarbons					1.7x10^{-3}	1.7x10^{-3}
Indium	1.5x10^{-6}	0.0011	2.1x10^{-6}	0.0015		
Iron	0.013	9.9*	0.030	22.*	3.7*	8.2*
Lanthanum	7.8x10^{-8}	5.8x10^{-5}	1.3x10^{-7}	9.1x10^{-5}	2.9x10^{-5}	4.4x10^{-5}
Lead	7.8x10^{-5}	0.058	3.9x10^{-4}	0.29	0.043	0.22
Lithium	0.0014	1.1*	0.0032	2.4*	0.68	1.5*
Magnesium	1.7x10^{-4}	0.12	4.2x10^{-4}	0.31	0.055	0.14
Manganese	6.5x10^{-6}	0.0048	2.5x10^{-5}	0.018	0.0026	0.0096
Mercury	2.7x10^{-6}	0.0020	1.3x10^{-5}	0.0097	7.6x10^{-5}	3.7x10^{-4}
Molybdenum	9.4x10^{-7}	7.0x10^{-4}	2.2x10^{-6}	0.0016	0.0012	0.0028
Nickel	0.0011	0.84	0.0073	5.4*	0.44	2.8*
Niobium	<7.4x10^{-8}	<5.4x10^{-5}	<8.1x10^{-8}	<6.1x10^{-5}		
Nitrogen oxides					56*	56*
Phosphorus	9.4x10^{-4}	0.69	0.0014	1.0*	0.52	0.75
Potassium	0.0010	0.77	0.0022	1.7*	0.41	0.88
Rubidium	2.1x10^{-7}	1.6x10^{-4}	7.5x10^{-7}	5.6x10^{-4}	9.2x10^{-5}	3.3x10^{-4}
Samarium	2.6x10^{-8}	1.9x10^{-5}	4.4x10^{-8}	3.3x10^{-5}		
Scandium	5.9x10^{-8}	4.4x10^{-5}	1.0x10^{-7}	7.4x10^{-5}	3.3x10^{-6}	1.9x10^{-5}
Selenium	1.8x10^{-5}	0.014	4.7x10^{-5}	0.035	0.016	0.041
Silicon	0.0021	1.5*	0.0025	1.9*	0.68	0.84
Silver	1.5x10^{-5}	0.011	6.3x10^{-5}	0.047		
Sodium	3.4x10^{-5}	0.025	1.7x10^{-4}	0.13	0.017	0.089
Strontium	3.5x10^{-5}	0.026	7.6x10^{-5}	0.056	0.011	0.025
Sulfur dioxide					49*	49*
Tantalum	4.3x10^{-8}	3.2x10^{-5}	5.9x10^{-8}	4.4x10^{-5}	2.4x10^{-5}	3.3x10^{-5}
Tellurium	2.2x10^{-7}	1.7x10^{-4}	2.7x10^{-7}	2.0x10^{-4}	1.3x10^{-5}	1.3x10^{-5}
Thallium	5.9x10^{-6}	4.4x10^{-4}	5.9x10^{-6}	0.0044	0.011	0.011
Thorium	9.6x10^{-6}	0.0072	2.1x10^{-5}	0.015	0.0042	0.0090
Tin	1.8x10^{-7}	1.3x10^{-4}	4.5x10^{-7}	3.3x10^{-4}	1.8x10^{-5}	4.6x10^{-5}
Titanium	8.0x10^{-5}	0.059	1.7x10^{-4}	0.13	0.035	0.075
Tungsten	6.5x10^{-7}	4.8x10^{-4}	7.4x10^{-7}	5.5x10^{-4}	1.8x10^{-4}	2.0x10^{-4}
Uranium	2.2x10^{-4}	0.16	8.1x10^{-4}	0.60	0.088	0.32
Vanadium	4.7x10^{-5}	0.035	9.0x10^{-5}	0.067	0.031	0.059
Zinc	2.7x10^{-5}	0.020	3.3x10^{-4}	0.24	0.023	0.30
Zirconium	1.0x10^{-5}	0.0078	2.0x10^{-5}	0.013	0.0014	0.0018
Stream flow rate (m^3/sec.), Q	387.	387.	387.	387.	114.8	114.8
Stream potential degree of hazard	0.045	33.	0.11	80.	130	160
No. entries compared to MATEs	50.	50.	50.	50.	48	48
Potential toxic unit discharge rate sum	17.	13000.	41.	30000.	14000.	18000

*Potential degree of hazard greater than one (1) indicates that this component may be an environmental hazard.

TABLE 88. SAM/IA ANALYSIS OF ATMOSPHERIC EMISSIONS FROM TREATED STRETFORD TAIL GAS, OXYGEN GENERATION AND FLARE

Constituent	Potential Degree of Hazard				
	Treated Stretford Tail Gas		Oxygen Generation	Flare	
	Health Based	Ecological Based	Health Based	Health Based	Ecological Based
Ammonia	0.078-0.44	4.0*-23.*			
Carbon dioxide	87*-88*		0.086	20*	
Carbon monoxide	0.00725-3.75*	0.0024-1.2*		114*	38*
Hydrocarbons (as ethane)	0.0016-0.57			ca. 4×10^{-4}	
Hydrogen sulfide	0.016-0.87				
Nitrogen oxides (as NO)	0.88-13.*				
Sulfur dioxide	0.00-0.35				
Stream flow rate (m^3/sec), Q =	82.1	82.1	87.2	0.131	0.31
Stream potential degree of hazard	92-100.	4.0-24.	0.086	134	38
No. of entries compared to MATEs	7.	2	1	3	1
Potential toxic unit discharge rate sum (m^3/sec)	7600-8400.	330.-2200.	7.5	17.5	5.0

*A potential degree of hazard greater than one (1) indicates that this constituent may be an environmental hazard.

5.2.4 Potential Ecological and Health Effects of Unregulated Air Pollutants

Table 89 lists unregulated air pollutants which may represent an environmental hazard in the SRC technology. Determinations of potential environmental hazard were made, based on application of MEG and SAM/IA methodologies. For some pollutant species, documented evidence was found suggesting possible environmental hazards at concentrations below existing MATE values. In those instances proposed MATES have been developed, based on evaluation of the documented evidence.

For titanium and vanadium, reevaluation of the MATES is recommended as shown in Table 90.

TABLE 90. SUGGESTIONS FOR MORE STRINGENT MATES FOR UNREGULATED AIR POLLUTANTS

Substance	Present Health-Based MATE	Proposed Health-Based MATE
Titanium	6000 $\mu g/m^3$	250 $\mu g/m^3$
Vanadium	500 $\mu g/m^3$	20 $\mu g/m^3$

The use of bioassays for the determination of the ecological and health hazards of various gaseous emissions to the environment from the SRC main unit operations and auxiliary processes is underway, as reported in Section 3.0. However, no formal reports have been issued as yet, although an acute inhalation study for vapor phase exposure has been completed (119). In a pilot study to determine appropriate dose levels for skin exposures to SRC wash solvent, a substantial number of the test animals developed corneal opacity presumably from a volatile substance transmitted from cage

TABLE 89. UNREGULATED AIR POLLUTANTS WHICH MAY CAUSE HEALTH OR ENVIRONMENTAL HAZARD

	Dust from Coal Preparation Module ($\mu g/m^3$)		Boiler Flue Gas ($\mu g/m^3$)		Health Based MATE ($\mu g/m^3$)	Ecological Based MATE ($\mu g/m^3$)	Comment
	Average U.S. Coal	Maximum U.S. Coal	Average	Maximum			
Aluminum	12-9000.	17-12000	4000.	5400.	5200.		Although aluminum is not a highly toxic element, large quantities may produce deleterious effects, such as pulmonary fibrosis from inhalation of aluminum powder. The TLV for Al_2O_3 is 5.3 mg Al (as Al)/m^3 (43).
Anthanthrene			2.8	3.6			This compound is carcinogenic and causes chromozone alterations. Mutagenic and teratogenic to mice. The EPA-NIOSH adjusted ordering number is 3,314,500 based on carcinogenicity.
Benzo(a)pyrene			1.6-10.	2.0-13.	0.02		This compound is carcinogenic and causes chromasome alterations. Mutagenic and teratogenic to mice.
Lithium	0.032-23	0.070-52	15.	33.	22.		The lithium ion is highly toxic to humans (43).
Titanium	0.48-350.	1.0-760	210	450	6000.*		Mice succumb to air levels of 10,000 $\mu g/m^3$ titanium chloride ($TiCl_4$) which is equivalent to 2,500 $\mu g Ti/m^3$.
Vanadium	0.023-17.	0.045-33.	15.	30.	500*	1.0	In air 0.5 to 1.0 $\mu g/m^3$ produces noticeable adverse effects on plants (43). Workers exposed to 200 to 500 $\mu g/m^3$ have suffered respiratory symptoms and eye effects have been reported at 100 $\mu g/m^3$.

*For reasons discussed under "Comments" we consider this MATE too high.

to cage of the test animals. Subacute inhalation studies are underway to determine if corneal opacity was caused by the test materials (119).

5.3 Impacts on Water

5.3.1 Summary of Water Standards

A summary of the most stringent water quality standards, based on the federal and selected state, regional, and international standards, are described. Supplemental information is presented in the Appendices.

5.3.1.1 Federal Standards or Criteria

Federal water standards may apply to either the ambient level or the effluent level of the pollutant. The major ambient standards are the National Primary Drinking Water Regulations. These regulations are applicable to the public water systems* and specify the maximum acceptable level of various contaminants. Table 91 lists these National Drinking Water Standards, along with comparable state standards.

Although there are no general federal water quality standards applicable to the national water or waterways, there are various water quality criteria (e.g., 1976, EPA Water Criteria, proposed). Criteria serve as guidelines and recommendations to states in setting discharge standards, but unlike standards or regulations, are not legally enforceable. Pursuant to Section 304(a) of the 1977 Clean Water Act Amendments, EPA must develop water quality criteria,

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*A public water system means piped water for human consumption if that system: (a) has at least 15 service connections; or (b) serves at least 25 people daily for at least 60 days per year.

TABLE 91. SUMMARY OF FEDERAL AND SELECTED STATE WATER QUALITY STANDARDS AND CRITERIA

Constituent	EPA National Interim Primary Drinking Water Standard	U.S. Public Health Service Drinking Water Standards, 1962	EPA REGIONS REPRESENTED BY SELECTED COAL-BEARING STATES														
			III^{a}	IV		V					VII					IX	X
			WV^{c}	KY^{d}	IL^{d}	IL^{e}	IN	OH^{f}	TX^{g}	CO	MT^{h}	ND	SD	UT^{j}	WY^{k}	AZ^{l,m}	AK^{n}
Arsenic	0.05	0.01	**	*	1.0	**		*	**		**	*		**		*	**
Barium	1.0	*	0.5	*	5.0	*		*	**			*		*		*	*
Cadmium	0.01	*	*	*	0.05	*		0.005	**		*	*		*		*	*
Chromium	0.05	*	*	*				0.01	**			*		*			*
Fluoride	1.4-2.4^{o}	0.6-1.7^{o}	1.0	1.0	1.4			1.0						0.01^{o}			
Lead	0.05	*	*	*	0.1	*		*	**		*	*		*		*	*
Mercury	0.002				0.0005			0.0005			0.001					0.005	
Nitrates (as N)	10		45		*			8.0				4.0	1e^{l}	45			
(as NO_3)		250							**					**			**
Selenium	0.01	*	*	*	1.0	*		0.005	**			*		*		*	*
Silver	0.05	*	*	*	0.005			*	**					*		*	*
Ammonia nitrogen (as N)								1.5				0.02	0.6^{l}				
Boron												0.5					
Chloride					1.0				**			100	100^{p}	**			**
Chromium (total		250	100		500	**											
trivalent)					1.0												
Copper		1.0			0.02				**		0.05	0.05		**		**	**
Cyanide (total)		0.01	0.025	0.025	0.025	**		0.005				**	0.02^{l}	**		0.2	**
(free)													0.005^{q}				
Hydrogen sulfide													0.002^{q}				
Iron (total)		0.3			1.0	**		**	**		**		0.2^{q}	**			**
(dissolved)											0.15						
Manganese		0.05			1.0	**		**	**					**			**
Nickel					1.0												
Oil & Grease						0.1		5.0							10		
Oxygen, dissolved																	
(daily ave.)				5.0	6.0			5.0					7.0^{q}				
(minimum)			5.0	4.0	5.0			4.0		6.0	3.0	5.0	6.0^{q}		5.6^{r}		5.0
pH (acceptable range)			6.0-8.5		6.5-9.0		6.0-9.0	6.0-9.0		6.5-8.5	6.5-9.5	7.0-8.5	6.6-8.6^{q}	6.5-8.5	6.5-8.5	6.5-8.6	6.5-8.5
(maximum change caused by discharges)											0.5					0.5	
Phenols		0.001	**		0.1	**		**	**			0.01		**		**	**
Phosphates												0.1	0.002^{q}				
Solids, total							250^{l}						1000^{l}				
(dissolved)		500		700	1000	**	1000^{m}	**	**			**	2000^{m}	**			**
(max. monthly ave.)				500													
Solids (total suspended)													30^{q}				
Sulfate		250			500				**					**			**
Temperature (°C) (maximum)			23;27^{s}							20		29.4	18.3^{q}		26;32^{t}	21;34^{t}	16;21^{u}
(maximum increase)			2.8	2.8	2.8					1.1		2.8			1.1;2.2^{u}	1.1;2.8	
Toxic/deleterious substances																	0.1
Turbidity increase (JTU)		5			1.0				**			10	10^{q}		10		**
Zinc		0.5							**		0.1	**		**		5.0	

Footnotes to Table 91

* Same as EPA National Interim Primary Drinking Water Standards
**Same as the U.S. Public Health Service Drinking Water Standard, 1962

[a] Pennsylvania water quality criteria are specific to the waterway and its uses, and are too varied to summarize here

[b] New Mexico water quality standard are specific to the use and river basin area, and are too varied to summarize here

[c] West Virginia water quality criteria are specific to the designated waterways. Criteria listed are for the Gauley River and tributaries

[d] General water quality standards

[e] Public and food processing water supply standards

[f] General water quality standards applicable within 500 yards of any public water supply intake in Ohio

[g] Domestic water supply criteria. It is the goal that the chemical quality of all Texas surface waters used for domestic raw water supply conform to the U.S. Public Health Service Drinking Water Standards, revised 1962, or latest revision. However, in some cases the only water source available cannot meet these standards and may be deemed suitable for use as a domestic raw water supply, where the chemical constituents do not pose a potential health hazard. Numerical criteria listed, other than the categories of Public Health Drinking Water Standards, are applicable to specific waters

[h] Montana utilizes specific water quality criteria for specific water - use classification. The metal limits below are for the Clark Fork River (mainstream) from the confluence of Cottonwood Creek to the Idaho state line

[i] Class I water quality standards

[j] Class "A" water, suitable

[k] Wyoming has three water classes, based on whether water is or has the potential to support game fish, nongame fish, or no fish (Classes I, II and III, respectively)

[l] Domestic supply

[m] Industrial supply

[n] Alaska has 7 water-use classifications and criteria. Criteria listed generally represent the most stringent

[o] Allowable limit depends on water temperature

[p] Limit of 100 mg/l for domestic supplies; for cold water permanent fish life propogation waters, total chlorine residual shall not exceed 0.02 mg/l

[q] Cold water, permanent fish life propagation waters

[r] 5.0 mg/l minimum in Class I waters; 6.0 mg/l minimum Class II waters

[s] May-November 27°C limit; December-April 23°C limit

[t] The lower temperature limit applies to cold water fisheries and the higher temperature to warm water fisheries

[u] 16°C limit in Class A waters; 21°C limit in Class B waters. Indicates the most and least stringent criteria

[v] Class A1 waters

for each of the 65 toxic pollutants (designated by (*) in Table 92) with recommended maximum permissible concentrations (where appropriate, zero).

In contrast to the Drinking Water Regulations, the EPA Effluent Standards are end-of-pipe limitations. The effluent standards specify the maximum permissible level of contaminants that are acceptable in effluents discharged from a specific source into navigable waters without regard to the quality of the receiving water. They prescribe effluent limitation guidelines for existing sources, standards of performance for new sources, and pretreatment standards for new and existing sources. EPA effluent standards are promulgated under legislation referred to generally as the Clean Water Act (or more specifically as the Federal Water Pollution Control Act [FWPCA]) along with 1972 and 1977 amendments to the Act.

No federal effluent regulations have yet been promulgated relative to the commercial SRC and related coal liquefaction technologies. Federal effluent guidelines and standards do, however, exist for several industries having operations and processes similar to SRC technology; these include coal preparation plants and storage facilities, petroleum refineries, by-product coking, and steam electric power generation. The effluent guidelines and standards for the above industries are summarized in Table 93.

(1) The Best Practical Control Technology currently Available (BPT) which existing plants were to meet by July 1, 1977 (compliance deadlines were in some cases extended to April 1, 1979);

TABLE 92. TOXIC POLLUTANTS - LIST OF 129 UNAMBIGUOUS PRIORITY POLLUTANTS, INCLUDING THE 65 CLASSES OF TOXIC CHEMICALS

Compound Name

1. *acenaphthene
2. *acrolein
3. *acrylonitrile
4. *benzene
5. *benzidine
6. *carbon tetrachloride (tetrachloromethane)

*Chlorinated Benzenes (other than dichlorobenzenes)

7. chlorobenzene
8. 1,2,4-trichlorobenzene
9. hexachlorobenzene

*Chlorinated ethanes (including 1,2-dichloroethane, 1,1,1-trichloroethane and hexachloroethane)

10. 1,2-dichloroethane
11. 1,1,1-trichloroethane
12. hexachloroethane
13. 1,1-dichloroethane
14. 1,1,2-trichloroethane
15. 1,1,2,2-tetrachloroethane
16. chloroethane

*Chloroalkyl ethers (chloromethyl, chloroethyl and mixed ethers)

17. bis(chloromethyl)ether
18. bis(2-chloroethyl)ether
19. 2-chloroethyl vinyl ether (mixed)

*Chlorinated naphthalene

20. 2-chloronaphthalene

*Chlorinated phenols (other than those listed elsewhere; includes trichlorophenols and chlorinated cresols)

21. 2,4,6-trichlorophenol
22. parachlorometa cresol
23. *chloroform (trichloromethane)
24. *2-chlorophenol

*Dichlorobenzenes

25. 1,2-dichlorobenzene
26. 1,3-dichlorobenzene
27. 1,4-dichlorobenzene

*Dichlorobenzidine

28. 3,3'-dichlorobenzidine

*Dichloroethylenes (1,1-dichloroethylene and 1,2-dichloroethylene)

29. 1,1-dichloroethylene
30. 1,2-trans-dichloroethylene
31. *2,4-dichlorophenol

*Dichloropropane and dichloropropene

32. 1,2-dichloropropane
33. 1,3-dichloropropylene (1,3-dichloropropene)
34. *2,4-dimethylphenol

*Dinitrotoluene

35. 2,4-dinitrotoluene
36. 2,6-dinitrotoluene
37. *1,2-diphenylhydrazine
38. *ethylbenzene
39. *fluoranthene

*Haloethers (other than those listed elsewhere)

40. 4-chlorophenyl phenyl ether
41. 4-bromophenyl phenyl ether
42. bis(2-chlorsiopropyl)ether
43. bis(2-chloroethoxy) methane

(continued)

TABLE 92. (continued)

Compound Name

*Halomethanes (other than those listed elsewhere)

44. methylene chloride (dichloromethane)
45. methyl chloride (chloromethane)
46. methyl bromide (bromomethane)
47. bromoform (tribromomethane)
48. dichlorobromomethane
49. trichlorofluoromethane
50. dichlorodifuloromethane
51. chlorodibromomethane
52. *hexachlorobutadiene
53. *hexachlorocyclopentadiene
54. *isophorone
55. *naphthalene
56. *nitrobenzene

*Nitrophenols (including 2,4-dinitrophenol and dinitrocresol)

57. 2-nitrophenol
58. 4-nitrophenol
59. 2,4-dinitrophenol
60. 4,6-dinitro-o-cresol

*Nitrosamines

61. N-nitrosodimehylamine
62. N-nitrosodiphenylamine
63. N-nitrosodi-n-propylamine
64. *pentachlorophenol
65. *phenol

*Phthalate esters

66. bis(2-ethylhexyl) phthalate
67. butyl benzyl phthalate
68. di-n-butyl phthalate
69. di-n-octyl phthalate
70. diethyl phthalate
71. dimethyl phthalate

*Polynuclear aromatic hydrocarbons

72. benzo(a)anthracene (1,2-benzanthracene)
73. benzo(a)pyrene (3,4-benzopyrene)
74. 3,4-benzofluoranthene
75. benzo(k)fluoranthene (11,12-benzofluoranthene)
76. chrysene
77. acenaphthylene
78. anthracene
79. benzo(ghi)perylene (1,12-benzoperylene)
80. fluorene
81. phenathrene
82. dibenzo(a,h)anthracene (1,2,5,6-dibenzanthracene)
83. Indeno(1,2,3-cd)pyrene (2,3-o-phenylenepyrene)
84. pyrene
85. *tetrachloroethylene
86. *toluene
87. *trichloroethylene
88. *vinyl chloride (chloroethylene)

Pesticides and Metabolites

89. aldrin
90. dieldrin
91. *chlordane (technical mixture and metabolites)

*DDT and metabolites

92. 4,4'-DDT
93. 4,4'-DDE (p,p'-DDX)
94. 4,4'-DDD (p,p'-TDE)

*Endosulfan and metabolites

95. a-endosulfan-Alpha
96. b-endosulfan-Beta
97. endosulfan sulfate

(continued)

TABLE 92. (continued)

Compound Name
*Endrin and Metabolites
98. endrin
99. endrin aldehyde
*Heptachlor and metabolites
100. heptachlor
101. heptachlor epoxide
*Hexachlorocyclohexane (all isomers)
102. a-BHC-Alpha
103. b-BHC-Beta
104. r-BHC (lindane)-Gamma
105. g-BHC-Delta
*Polychlorinated biphenyls (PCB's)
106. PCB-1242 (Arochlor 1242)
107. PCB-1254 (Arochlor 1254)
108. PCB-1221 (Arochlor 1221)
109. PCB-1232 (Arochlor 1232)
110. PCB-1248 (Arochoor 1248)
111. PCB-1260 (Arochlor 1260)
112. PCB-1016 (Arochlor 1016)
113. *Toxaphene
114. *Antimony (total)
115. *Arsenic (total)
116. *Asbestos (fibrous)
117. *beryllium (total)
118. *Cadmium (total)
119. *Chromium (total)
120. *Copper (total)
121. *cyanide (total)
122. *Lead (total)
123. *Mercury (total)
124. *Nickel (total)
125. *Selenium (total)
126. *Silver (total)
127. *Thallium (total)
128. *Zinc (total)
129. *2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD)

*Specific compounds and chemical classes as listed in the consent decree.

TABLE 93. EPA EFFLUENT STANDARDS FOR COAL LIQUEFACTION RELATED TECHNOLOGIES (116)

Category	Subcategory	Basis	Pollutant or effluent characteristics	Maximum for any one day	Average of daily values for 30 consecutive days shall not exceed:
Coal Mining (Part 434)	A. Coal Preparation Plant	BPT	No discharge of pollutants		
Regulations expressed in mg/l	C. Acid on Ferruginous Mine Drainage	BPT	Iron, Total	7.0	3.5
			Iron, Dissolved	0.60	0.30
			Manganese	4.0	2.0
			TSS	70.0	35.0
Steam Electric Power Generating (Part 423)	A. Generating Unit	BPT, BAT, NSPS	pH all discharges	6.0-9.0	
Regulations concentrations expressed in mg/l			Polychlorinated Biphenyl compounds	No discharge	
			TSS	100	30
			Oil and grease	20	15
			Total copper from metal cleaning wastes or boiler blowdown	1.0	1.0
Steam Electric			Free available chlorine from cooling tower blowdown	0.5	0.2
			Materials added for corrosion inhibition in cooling tower blowdown	No detectable amount	

(continued)

TABLE 93. (continued)

Category	Subcategory	Basis	Pollutant or effluent characteristics	Maximum for any one day	Average of daily values for 30 consecutive days shall not exceed:
Petroleum Refining (Part 419) For typical lube refining, (19875 m^3 per stream · day throughput) (Regulations expressed in kg/km^3 of feedstock)	A. Topping (for discharges other than runoff or ballast)	NSPS	BOD_5	11.8	6.3
			TSS	8.3	4.9
			COD	61	32
			Oil & Grease	3.6	1.9
			Phenolic compounds	0.088	0.043
			Ammonia (as N)	2.8	1.3
			Sulfide	0.078	0.035
Petroleum Refining (Part 419) continued			Total chromium	0.18	0.105
			Hexavalent chromium	0.015	0.0068
Iron and Steel (Part 420) (Regulations expressed in kg/kkg of product)	A. By-product Coke	BAT, NSPS	Cyanides amenable to chlorination	0.0003	0.0001
			Phenol	0.0006	0.0002
			Ammonia	0.0126	0.0042
			Sulfide	0.0003	0.0001
			Oil & Grease	0.0126	0.0042
			TSS	0.0312	0.0104
	H. Open-Hearth Furance	BAT, NSPS	TSS	0.0156	0.0052
			Fluoride	0.0126	0.0042
			Zinc	0.0030	0.0010

(2) The Best Available Control Technology Economically Achievable (BAT or BACT) which all plants must meet by July 1, 1984;

(3) The New Source Performance Standards (NSPS), utilizing BAT, which apply to new plants and must be met upon startup.

For each industrial category regulated, the U.S. EPA has published one or more development documents describing the industry, its pollutants and wastewater flows, and the process technologies considered in the establishment of BPT, BAT, and NSPS.

Guidelines are promulgated on a mass discharge basis, limiting the discharge of regulated process wastewater pollutants according to the scale of industrial production, raw material usage or similar parameter of individual industrial plant activity. Although the effluent guidelines are expressed as mass discharge units, they are derived from expected concentrations of process wastewater pollutants achievable by application of appropriate control technology. Further, most development documents report expected wastewater volumes associated with the point source discharges, expressed as volume of liquid per unit of industrial activity. For example, effluent guidelines for the by-product coke industry (subcategory of iron and steel manufacturing) are expressed in allowable milligrams of each process wastewater pollutant regulated per 1000 kilograms of product produced. By dividing the mass discharge effluent limitation by the wastewater volume per unit of industrial activity, equivalent standards expressed as concentration units can be calculated (120):

$$\frac{\text{Limitation, in mg/unit of activity}}{\text{Waste Volume, in l/unit of activity}} = \text{mg/l}$$

Thus, it is simple to convert mass discharge limits to concentration limits for each process wastewater pollutant of each industrial category and subcategory.

5.3.1.2 Federal Legislation

5.3.1.2.1 Recent Amendments to the Clean Water Act

The 1977 amendments to the Clean Water, or Federal Water Pollution Control Act (FWPCA), along with the 1972 amendments, establish long-range national goals to limit point source effluent concentrations and set forth the principal mechanisms for the control of water pollution from industrial sources. Various sections of the FWPCA which may have regulatory impact for the development and operation of commercial SRC facilities are briefly summarized below, along with the present status of the regulation.

Section 307(a), Toxic Pollutant Effluent Standards, requires the EPA administrator to publish a list of toxic pollutants for which an effluent standard will be established. A list of 129 unambiguous priority pollutants has been established, based on an expansion of the original list of 65 classes of toxic chemicals (see Table 92). Toxic Pollutant Effluent Standards have, however, been established for only six chemicals. Formulation of aldrin/dieldrin, DDT (DDE, DDD), and PCBs was prohibited outright as were discharges of endrin and toxaphene from formulators. Benzidine dischargers, and manufacturers of endrin and toxaphene were required to meet standards based on the best available technology.

Section 311, Oil and Hazardous Substance Liability, provides for "designation of hazardous substances" which, when discharged (including spills), present an imminent and substantial danger to the public health or welfare, and for "penalties for discharges" of such hazardous substances from onshore and offshore facilities and vessels.

EPA proposed a hazardous spills program on March 13, 1978 which was rejected by the courts on August 11, 1978. EPA had designated 271 chemicals as hazardous substances, classifying the substances into five categories according to toxicity. These rejected regulations would have provided different penalty and reporting requirements for discharges of various substances based on multiples of a "one-pound" unit of measure (121).

The oil and hazardous substance liability could be of particular significance to the coal liquefaction technology, since many of the constituents in the liquefaction product and by-products are classified as hazardous substances. Section 311(c) of the Act stipulates the development of a National Contingency Plan to minimize damage to the aqueous environment from oil and hazardous substance discharges. Action plans for containment, dispersal and removal are required, with particular reference to the discharge of oil and hazardous substances which may affect natural resources belonging to, or under the exclusive management authority of the U.S. and those under the Fishery Conservation and Management Act of 1976 (122).

Sections 301 and 304, Effluent Limitations and Guidelines, stipulate that technology-based effluent limitations and guidelines are required for all pollutants, including toxic substances, from point-source discharges. These limitations are to be accomplished in phases. The first phase of industrial cleanup required industrial discharges to use best practical control technology (BPT) by July 1, 1977. For the second phase of cleanup, the amendments specify three classes of pollutants: toxic, conventional and nonconventional.

For the 65 classes of chemicals listed as toxic in Table 92, industry is required to apply BAT and be in compliance by July 1, 1984. Should the EPA set a toxic standard (under Section 307(a)) instead of BAT, industry must comply within 1 to 3 years after the toxic standard is set.

The EPA must promulgate BAT regulations for any chemical added to the list of 65 classes of toxic pollutants as soon as practicable. In this case industry must comply not later than 3 years after the BAT regulation was set. But, if the EPA should set a toxic standard instead of BAT, industry shall comply within 1 to 3 years after the toxic standard was set.

For conventional pollutants the EPA must set effluent limitations requiring best conventional pollutant control technology, and industry must comply by July 1, 1984. The level of pollutant control can be no less than BPT, and as high as BAT (122).

The EPA, on July 28, 1978, designated the following four pollutants as "conventional" (123):

- Biochemical oxygen demand (BOD)
- Total suspended solids (nonfilterable) (TSS)

- Fecal coliform bacteria
- pH (hydrogen ion)

Three additional pollutants (shown below) were proposed on August 4, 1978 to be designated as conventional (123):

- Chemical oxygen demand (COD)
- Phosphorus
- Oil and grease

For all unconventional pollutants (i.e., those other than toxic or conventional) industry must comply with BAT no later than July 1, 1987. These controls are subject to strict waiver requirements.

Section 306 of the Clean Water Act provides for the development of Standards of Performance for New Point Source Discharges, giving consideration to control technology, processes, and operating methods, among other alternatives.

Sections 307(b) and (c) require that Pretreatment Standards be promulgated for discharge of toxic substances and other pollutants into publicly-owned treatment works. These standards would prevent the discharge of any pollutant known to be incompatible with such treatment works. Under the new amendments, localities may revise pretreatment requirements for toxic pollutants, particularly where the municipal treatment works removed all or part of the toxicants (122).

Section 402, the National Pollutant Discharge Elimination System (NPDES), requires that the EPA, or a state having an EPA approved permit program, shall issue a permit for the discharge of point source pollutants into navigable waters. The NPDES permit must also be in compliance with all applicable requirements under Sections 301, 302, 306 to 308, and 403 of the Clean Water Act.

It appears that the weakest areas in the statutory control of toxic water pollutants include the following:

- Accidental spills
- Nonpoint sources of overland flows
- Stormwater runoff

With regard to spills, further implementation of Section 311 of the Clean Water Act may strengthen controls in this area. With respect to nonpoint sources of overland flows (agricultural, silvicultural, construction and mining runoff) and stormwater runoff, Section 208 programs will culminate in guidelines for controlling nonpoint sources. These 208 plans will be further developed by state and local authorities.

5.3.1.2.2 Proposed Revision of the National Pollutant Discharge Elimination Systems

The EPA recently proposed extensive revisions to the National Pollutant Discharge Elimination Systems (NPDES) as a whole (124). In addition to overall revision, the following two regulations, under the NPDES were proposed:

(1) Requirements for spill prevention control and countermeasure plans (SPCC) to prevent discharges of hazardous substances from facilities subject to permitting requirements (125).

(2) Criteria and standards for imposing best management practices (BMP) for subsidiary, ancillary industrial activities to prevent the release of toxic and hazardous pollutants to surface waters (126).

Spills of SRC product could be a major ecological and health hazard. The above regulations could contribute control measures to decrease the possibility of such spills and/or the hazard it would present to the environment. Best management practices (BMP) refers to methods, measures or practices to prevent or reduce the introduction of pollutants to waters of the United States. BMPs include but are not limited to treatment requirements, operating and maintenances procedures, schedules of activities, prohibition of activities, and other management practices to control plant site runoff, spillage or leaks, sludge or waste disposal, and drainage from raw material storage. They may be imposed in addition to or in the absence of effluent limitations, standards or prohibitions.

The SPCC plan approach used in these proposed NPDES regulations is similar to the one developed and used in EPA's oil pollution prevention regulation (127). The SPCC plan would be developed by the owner or the operator of a facility, or by his/her engineer, in accordance with guidelines contained in the regulations. The plan would have to be certified by a registered professional engineer and be implemented by the owner or operator. Compliance with SPCC plan requirements would be established as a minimum level of control for best management practices (BMP) plans. The failure to develop and implement an adequate BMP plan, as well as the discharge of pollutants in contravention of an adequate BMP plan, will constitute a permit violation and subject the permittee to enforcement action.

5.3.1.2.3 Other Federal Statutory Requirements Relating to Toxic and Hazardous Water Pollutants

The Clean Water Act provides a broad spectrum of mechanisms for the control of pollutants while other federal laws are more narrowly drawn and focus on individual sources of pollution such as transportation.

The Marine Protection Research and Sanctuaries Act of 1972 controls the ocean dumping of matter of any kind, including radioactive materials (but excluding oil), sewage from vessels, and effluents regulated by FWPCA, the 1899 Rivers and Harbors Act, or the Atomic Energy Act. Permits may be issued by the EPA for the transportation and dumping of materials (other than radiological, chemical and biological warfare agents and dredged material) should the Administrator conclude that such dumping will not unreasonably endanger or degrade human health and welfare.

The Resource Conservation and Recovery Act of 1976 controls water pollution indirectly by requiring a regulatory system for the treatment, storage, and disposal of hazardous wastes. Hazardous waste is defined as a solid waste generated by industrial, commercial, mining and agricultural operations that, because of its quantity or characteristics (e.g., bottom ash or fly ash containing radioactivity and suspected carcinogens), may be hazardous to human health or to the environment. Subtitle C of the 1976 Act requires the EPA administrator to:

- Promulgate criteria and regulations that identify the characteristics of hazardous waste, and list particular hazardous wastes.

- Promulgate standards, regulations, and manifests applicable to those who generate, transport, treat, store or dispose of hazardous wastes. These procedures will specify record keeping, labeling, reporting, monitoring and inspection practices and compliance with requirements for permits. Also required is the promulgation of guidelines to assist the development of state hazardous waste programs. These programs must fulfill the criteria of consistency, equivalency, and adequacy of enforcement. For example, regulations developed by EPA relative to transporters of hazardous wastes subject to the Hazardous Materials Transportation Act, must be consistent with the requirements of that Act. EPA must also integrate all provisions of the Resource Conservation Act and avoid duplication (where practicable) with the Clean Air Act, the Clean Water Act, Safe Drinking Water Act, and other acts that grant regulatory authority to EPA.

The Toxic Substances Control Act (TSCA) of 1976 authorizes the EPA to require the testing of suspected chemicals to determine the extent of the toxicity. This broad discretionary power is highly relevant to certain potentially toxic inorganics and organics known to occur in certain waste streams and products of the SRC technology. The EPA administrator may prohibit or limit the disposal of a chemical or a mixture of chemical substances, when he finds that there is a reasonable basis to conclude that a chemical substance or a mixture poses an unreasonable risk of injury to human health or to the environment as a whole. The term "mixture" is defined as a combination of chemical substances that is not the result of a chemical reaction.

The major importance of TSCA is that it stands as an alternative statutory control, if adequate controls cannot be developed for a chemical substance through the Clean Water or Safe Drinking Water Act (122).

5.3.1.3 State Standards or Criteria

A majority of states have established water quality standards which are applicable, for the most part, to existing receiving waters of the state. These water quality standards for selected states are summarized and compared to the EPA National Interim Drinking Water Standards and the U.S. Public Health Service Drinking Water Standards, 1962, in Table 91.

States may have also established effluent standards, imposing discharge limitations on various industries. In addition, states generally require a discharge permit from industrial dischargers. The primary mechanism for controlling effluents into receiving waters is therefore by enforcement of the conditions imposed by a required discharge permit.

Water quality standards highlighted in this report are those of the coal-producing states that may affect future commercial SRC operations. The several factors that are determinant to the establishment of standards applicable to state waters of all classifications are as follows:

States by EPA Region		Beneficial Uses	Mixing Zone	Stream (Use) Classification
III	Pennsylvania	-	-	*
	West Virginia	-	-	*
IV	Kentucky	-	-	*
V	Illinois	*	*	-
	Indiana	*	*	-
	Ohio	*	*	-
VI	New Mexico	-	-	*
VIII	Montana	*	-	-
	North Dakota	*	-	-
	Utah	-	-	*
	Wyoming	*	-	-
IX	Arizona	*	-	-
X	Alaska	*	-	-

5.3.1.3.1 Effluent Standards of The States

In contrast to the federal effluent guidelines which apply to specific industrial categories, the state numerical effluent standards for the seven coal-producing states (Table 94) apply equally to all point source discharges. In some states, the effluent standards are applicable only for discharges to selected bodies of water. Table 94 shows the coal-producing states that have issued numerical effluent standards for specific pollutants.

TABLE 94. NUMERICAL EFFLUENT STANDARDS OF COAL-PRODUCING STATES

	EPA REGIONS REPRESENTED BY SELECTED STATES						
	III		IV	V		VIII	
Pollutant	Maryland	Virginia	Kentucky	Illinois	Colorado	Montana	North Dakota
Arsenic	-	-	-	0.25	-	Avg./d, 0.01^a Max. 0.016^a	-
Barium	-	-	-	2.0	-	-	-
BOD					45(7 day avg.) 30 (30 day avg.)		
Cadmium	-	-	-	0.15	-	Avg./d,0.01^a Max. 0.01^a	-
Chromium	-	-	-	0.30(hex.)	-		-
Copper	-	-	-	1.0	-	Avg./d,0.05-0.09^b Max.,1.3-2.2^b	-
Cyanide	-	-	-	0.025	-	-	-
Fluoride	-	-	-	15.0	-	-	-
Iron	-	-	-	2.0	-	Avg./d,0.3-1.3^b Max.,1.3-2.2^b	-

(continued)

TABLE 94. (continued)

EPA REGIONS REPRESENTED BY SELECTED STATES

	III		IV	V		VIII	
Pollutant	Maryland	Virginia	Kentucky	Illinois	Colorado	Montana	North Dakota
Lead	-	-	-	0.100	-	Avg./d,0.3-0.10^b Max.,0.05-0.10^b	-
Manganese	-	-	-	1.0	-	-	-
Mercury	-	-	-	0.0003	-	Avg./d,0.001^b Max.,0.001^b	-
Nickel	-	-	-	1.0	-	-	-
Oil	30.0	-	-	15.0	10.0(7 day avg.)^c 10.0(30 day avg.)^c	-	-
pH	6.0-8.5^d	6.0-8.5^c	6-9(7 day avg.) 6-9(30 day avg.)	5-10	6-9(7 day avg.) 6-9(30 day avg.)	-	-
Phenols	-	-	-	0.30	-	-	-
Selenium	-	-	-	1.0	-	-	-
Silver	-	-	-	0.10	-	-	-

(continued)

TABLE 94. (continued)

EPA REGIONS REPRESENTED BY SELECTED STATES

	III		IV	V		VIII	
Pollutant	Maryland	Virginia	Kentucky	Illinois	Colorado	Montana	North Dakota
Total Dissolved Solids	-	-	-	750-3500	-	-	-
Total Suspended Solids	400^d	4.0^c 0.0^h	45(7 day avg.) 30(30 day avg.)	$5\text{-}34^f$	45(7 day avg.) 30(30 day avg.)	-	10^r
Zinc	-	0.5^i	-	1.0	-	Avg./d,$0.01\text{-}0.3^b$ Max.,$0.2\text{-}1.0^b$	-

[a] For Clark Fort River only.

[b] For segments of Clark Fork River.

[c] There shall be no visible sheen.

[d] Effluent limitation.

[e] For the entire Chickahominy watershed above Walkers Dam.

[f] Depends on body of water being discharged to

[r] Municipal wastes

[h] For the Rappahanock River Basin above proposed Salem Church Dam

[f] Applies to all bodies of water.

5.3.1.3.2 State Water Quality Standards

A comparison of the water quality standards of the various coal producing states is shown in Table 91, along with the EPA National Drinking Water Standards and the Public Health Drinking Water Standards. In general, the state standards are quite similar to the two national standards, although states often establish numerical and nonnumerical standards for additional contaminant categories. An individual state may also promulgate a number of different water quality standards, each of which may apply specifically to a particular waterway or a particular intended use of that water (e.g., swimming, fishing, and domestic water supply used). Those standards pertaining to domestic water supply or game fish breeding waters are, as a rule, more stringent than, for example, those pertaining to industrial or agricultural uses. A comparison of two Illinois standards in Table 91 (the general water quality standards are the public food processing water supply standards) illustrate the application of more stringent regulation to drinking water.

EPA Region III (Pennsylvania and West Virginia - Pennsylvania water quality criteria are based upon water use and are applicable to specific waterways. These criteria are too numerous and varied to incorporate into the summary table.

West Virginia has water quality criteria similar to those of Pennsylvania. Criteria for the Gauley River and tributaries were chosen for representation in Table 91 due to their acceptability for all water use classifications.

EPA Region IV (Kentucky) - Kentucky water quality standards vary with stream use classification. The general water quality standards are shown in Table 91.

EPA Region V (Illinois, Indiana, and Ohio) - Illinois general water quality standards and the public and food processing water supply standards are shown in Table 91. Effluent standards are given in Table 94. The rules and regulations indicate that dilution of the effluent from a treatment works or from any wastewater source is not acceptable as a method of treatment of wastes in order to meet the effluent standards. It is further stated that the most technically feasible and economically reasonable treatment methods should be employed to meet the specified effluent limitations.

Indiana water quality standards state criteria to be considered when determining a mixing zone but describe no absolute zone, reasoning that too many variables are involved. The numerical criteria are limited and apply primarily to changes in temperature, pH and dissolved oxygen. The criteria also state that toxic substances shall not exceed one-tenth of the 96-hour median tolerance limit.

Ohio water quality standards depend on water use and mixing zone (which is formulated for specific discharges and locations) rather than a generalized definition. Table 91 presents the general water quality standards applicable within 500 yards of any public water supply intake in Ohio.

EPA Region VI (New Mexico and Texas) - New Mexico water quality standards, specific to the water use and the river basin, were too numerous and varied to present in the state standards summary table.

Texas water standards consist of three parts: general criteria, numerical criteria and water uses. The latter two are highly stream-specific, similar to the Pennsylvania legislation. Water quality parameters and uses for the domestic water supply criteria are shown in Table 91. It is the goal that the chemical quality of all Texas surface waters used for domestic raw water supply conform to the U.S. Public Health Service Drinking Water Standards, revised 1962, or latest revision. However, in some cases the only water source available cannot meet these standards and may be deemed suitable for use as a domestic water supply, where the chemical constituents do not pose a potential health hazard. Numerical criteria listed, other than the categories of Public Health Drinking Water Standards, are applicable to specific waters. It should be noted that Texas has one of the warmest climates among those states considered. Natural water temperature may exceed 96°F (37.7°C). For this reason the 90 degree maximum temperature suggested by the National Technical Advisory Committee does not apply. A maximum temperature increases of 3 F° (1.7 C°) is permitted for fresh waters, 5 F° (2.8 C°) for saline waters. Applicable water quality standards for various water use class categories in Wyoming are shown in Table 91.

Stream quality criteria are dependent upon stream classification. Class "A" waters are to be suitable without pretreating for a variety of uses including domestic water supply and propagation of fish and wildlife. Such waters are to be free from organic substances measured by biochemical oxygen demand. A pH range of 6.5 to 8.5 is to maintained. Physical characteristics and chemical concentration standards are the same as prescribed by "Public Health Service Drinking Water Standards, 1962."

Wyoming water quality standards which may affect future commercial SRC operations are summarized in Table 91. Wyoming waters are classified as having potential to support game fish (Class I), potential to support nongame fish (Class II), or as not having the potential to support fish (Class III). In addition, waters designated as part of the public water supply must meet the most recent Federal Drinking Water Standards.

EPA Region VIII (Colorado, Montana, North Dakota, South Dakota, Utah and Wyoming) - Both water quality standards and effluent limitations have been promulgated for Colorado, as shown in Tables 91 and 94 respectively.

Montana's water quality policy consists of general water quality criteria and specific water quality criteria which correspond to the various water-use classifications. The metals limits listed in Table 91 are for the Clark Fork River (mainstream) from the confluence of Cottonwood Creek to the Idaho state line.

North Dakota water quality is dependent upon water classification. Mixing zone guides are described in preference to defining a mixing zone applicable to every situation. Applicable criteria for Class I waters are shown in Table 91.

EPA Region IX (Arizona) - Water quality standards for Arizona are established for surface waters with specific uses. Applicable standards for domestic and industrial waters are compiled in Table 91.

EPA Region X (Alaska) - Alaska has seven water use classifications and criteria. The criteria listed in Table 91 generally represent the most stringent.

With respect to toxic and hazardous water pollutants, nonnumerical standards have been proposed by Pennsylvania and West Virginia (EPA Region III); Kentucky (Region IV); Ohio (Region V); Colorado, Montana, North Dakota, South Dakota, Utah and Wyoming (Region VIII); and Arizona (Region IX).

Numerical standards for toxic substances have been issued by Illinois (Region V), Montana (pegged to bioassay and Public Health Service Drinking Water Standards), Indiana (pegged to Drinking Water Standards of USPHS), Texas and Montana. The state of Alaska has proposed neither numerical or nonnumerical standards for toxic and hazardous substances.

A comprehensive summary of various water qulaity and effluent standards of coal producing states is presented in the document, Environmental Standards Applicable to Coal Conversion Processes (118).

5.3.2 Comparisons of Waste Streams with Effluent Standards

The flows of effluents and accidental spills from basic unit operations and various auxiliary (required for and incidental to the SRC system) are combined and routed to the wastewater treatment facility, as shown in Figure 63. The primary focus therefore becomes the quantity and composition of effluents and discharges from the wastewater treatment facility that may eventually interact with aquatic and land environments. In conformity with the earlier discussion of emissions to the atmosphere effluents from auxiliary processes are categorized in terms of: (1) those that are clearly required for, and (2) those that are incidental to the primary functions of the SRC-II system. Streams shown in Figure 63 are characterized in Section 3.0.

5.3.3 Impact on Ambient Water Quality

Table 95 lists the concentration of water pollutants for which regulations are available, the applicable MATEs, and comments on the toxicity of each pollutant. In a few cases, for reasons listed as "comments", in our opinion, reevaluation of MATE values should be considered. In these cases the toxicity of this pollutant predicted by the SAM/IA method may be too low. Table 96 shows these MATEs and recommendations for proposed MATEs. Our recommendations are meant to be multiplied by a dilution factor before they are applied to the waste streams; hence, they are analogous to the ecological-based MATE. In order to determine the health-based MATE, simply multiply the proposed (ecological) MATE by 10 (i.e., the worst case dilution factor).

Estimates of pollutant levels in the water-bound waste streams and elements of the SAM/IA analysis of these streams are given in Tables 97 and 98. The SAM/IA analysis indicates that aluminum, calcium, chromium, iron, manganese, mercury, nickel, and sulfate may be a problem in the coal pile drainage. Mercury may be a problem in the ash pond effluent. Phenols, cresols, xylenols, C^3-phenols, naphthalene, naphthols, bismuth, calcium, and iron may be a problem in the wastewater effluent. In addition, we have indicated, in Sections 5.3.2 and 5.3.4, some problem areas in which the potential degree of hazard predicted by the MEG-SAM/IA approach may be underestimated.

TABLE 95. REGULATED WATER POLLUTANTS WHICH MAY EXCEED STANDARDS AND/OR WHICH MAY CAUSE HEALTH OR ENVIRONMENTAL HAZARD

				Applicable MATE			Critical Conc.[b]		FWPCA				
Pollutant	Coal Pile Drainage	Ash Pond Effluent	Wastewater (Avg. max.)	Health Based	Ecological Based	Drinking Water	Fresh Water	Marine Water	Surface Water	Irrigation	Public Water Supply Intake	Potable Water	Livestock Drinking Water
Aluminum	7.3×10^{5}	700-2000	250.(340.)	$8.0\times10^{4*}$	1000*	10.							
Barium	100.	200.	125.(250.)	5000.*	2500.*	1000.			1000.				
Beryllium	10.	<10.		30.*	55.*	1000.	100.	20.				1000.	
Cadmium	4.	1.		50.*	10*	10		5.	10.	5.	100.		50.
Chlorine	1.0×10^{5}	5000-12000	6500(11000)	1.3×10^{6}	$10.^{\beta}$	250,000							
Chromium	2000.	20.-45.	90(220)	250.*	250.*	50.	5.	0.06	50	5000.	50	20.	1000.
Copper	1500.	20-50	11(30)	5000.*	50.*	100(1000)	20.	1.	1000.	200	1000.	10.	500.
Iron	9×10^{6}	230-240	560(1250)	1500.	250.	(300)							
Lead		10-25		250.*	50.	50.	10.	5.	50.	5000.	50.	10.	100.
Magnesium	6.5×10^{4}	1000-2000	1800(4500)	9.0×10^{4}	8.7×10^{4}	10000.							
Manganese	6.5×10^{4}	1-10.	20.(77.)	250.	100.	50.	10.	2.	50.	2000.		10.	
Mercury	14.	0.4-38.	3.9(19.)	10.*	250.*	2.	1.	5×10^{-5}			2.	2.	1.
Nickel	1000.	50-70.	0.015(0.098)	250.	10.	50.	5.	1.		500.		50.	
Selenium	20.	11.-16.	0.80(2.1)	50.*	25.*	10.	1.	2.	10.	50.	10.	10.	50.
Silver		< 10.		250.*	5.0*	50.	1.	5.			0.5	1.2	
Sulfur	2.6×10^{6}	$8.7\text{-}15.6\times10^{4}$											
sulfur dioxide				2.0×10^{5}									
hydrogen sulfide				2.3×10^{4}									
sulfate				1.5×10^{4h}	$450.^{h}$	(25000)							
Zinc	5100.	40.-50.		$2.5\times10^{4*}$	100.*	5000.			5000.	5000.		50.	25000
pH	2.8-7.8	9.4-114									5-9		
Suspended solid		$1\text{-}182.\times10^{3}$											
Phenol			390	5.0	500.*	1.							
Cresols			940	5.0	500.	1.							
Xylenol			380	5.0	500.	1.							
C_3-phenols			90	5.0	500.	1.							

TABLE 95. (continued)

	Comments
Aluminum	Growth reduction in wheat and orange seedlings were reported in nutrient solutions containing 100 µg/l aluminum. A concentration of 70 µg/l is toxic to the stickleback fish, Gasterosteus aculeatus (43).
Barium	One hundred µg/l barium reduces the heterotrophic activity of freshwater microflora (109).
Beryllium	Some varieties of citrus fruit seedlings show toxic effects at concentrations of 2.5-5.0 µg/l beryllium (154). The 96-hour LC_{50} for the fathead minnow is 150 µg/l as $BeCl_2$ in soft water. Nutrient solutions containing 500 µg/l beryllium reduced the growth of bush beans (43).
Cadmium	Five µg/l cadmium in drinking water of rats for one year apparently results in hypertension. Reproduction of Daphnia magna was reduced at a cadmium concentration of 0.5 µg/l. Five months exposure to cadmium concentrations of 0.02 to 10 µg/l increased mortality of crayfish, Cambarus latimanus, but had little effect on growth or temperature tolerance. In freshwater systems, 0.01 g/l cadmium inhibited the growth of floating aquatic plants. The 200 hour LC_{50} for steelhead trout, Salmo gairdneri, varies from 0.9 to 1.5 µg/l depending on the age of the fish (108). The 200 hour LC_{50} for chinook salmon, Oncorhynchus tshawytscha, varous from 1.6 to 2.3 µg/l for fish from 3 weeks to 18 months old (IV-21). Adult coho salmon, Oncorhynchus kisutch, show a 200 hour LC_{50} of 3.3 µg/l (108). The grass shrimp, Daphnia magna, show a 3 week LC_{50} of 1.7 µg/l (153). The most stringent state standard for cadmium is 10. The EPA Water Quality Criteria for fresh soft water is 0.4-4, and the criteria for fresh hard water is 1.2-12.
Chlorine	The preliminary draft of the EPA Quality Criteria for water indicates that 3 µg/l chlorine would not harm salmonid fishes and that a level of 10 g/l should be satisfactory for other fishes. Lethal concentrations for brook trout, Salvelinus fontinalis; brown trout, Salmo trutta; grass shrimp, Daphnia magna; and seeweed hoppers, Gammarus pseudolimnecus ranged from 14 to 20 µg/l (43,47).
Chromium	Mean brood size of the marine polychate, Heanthes arenaceodentata, is reduced by 12.5 µg chromium/liter (108). The 48-hour LC_{50} for the grass shrimp, Daphnia hyalina, is 22 µg/l (108). The algae lethal level is 32-6400 µg/l (43,154). The lethal level for for oysters is 10-12 µg/l (43,154).
Copper	Photosynthesis of certain species of phytoplankton can be inhibited by as little as 6 µg Cu/l (156) and growth reduction can occur at 10 µg/l (155). Toxic effects of copper on many aquatic organisms range from 0.04 to 10 µg/l (108,109). With many more toxic effects being noted in the range 10 to 100 µg/l (108,112).

(continued)

TABLE 95. (continued)

	Comments
Iron	Levels of more than 1000 µg/l inorganic iron and compounds (as iron) are toxic to certain sensitive plants while animals are unaffected by levels of 100 µg/g animal. The preliminary draft of the EPA quality criteria for water indicates that 300 µg/l iron is satisfactory for public water supplies and that 1000 µg/l should allow fish and wildlife propagation. The 1972 EPA Water Quality Criteria indicates that a level of 5000 µg/l is satisfactory in waters to be used for irrigation. Iron levels of 1.5-1.0 µg/l stimulates the growth of the algae, Chlorella pyrenoides (109) which can lead to eutrophication. The lowest LC_{50} is for the mayfly, Ephemarella subvaria, at 320 g/l for 96-hours; the next lowest known iron concentrations showing a biological effect is 3000 µg/l which causes reproductive impairment in seaweed hoppers, Cammaride, after 4 months (112).
Lead	A lead concentration of 100 µg/l inhibits 50 percent of the light-induced oxygen evolution in several species of freshwater algae (110). The toxicity of lead to aquatic organims generally occurs at concentrations greater than 10 µg/l (112). Daphnia showed 16 percent reproductive impairment in 3 weeks at a concentration of 30 µg/l (112). Sensitive fish species (e.g., trout and salmon) suffer fry mortality at concentrations ranging from 10 to 1000 µg/l (112).
Magnesium	At 7200 µg/l, magnesium inhibits the growth of Botryococcus (43). The concentrations of calcium and magnesium in water influence the toxicity of heavy metals (43).
Manganese	Levels of 5 to 20 µg/l manganese stimulates the growth of the alga, Dunaliella tertiolecta, and inhibits the growth of Anabaena sp. and Aphanizonmenon sp. (109).
Mercury	The proposed EPA 1976 Water Quality Criteria is 2.0 µg mercury/l for health protection, 0.05 µg/l for protection of freshwater life and wildlife, and 0.10 µg/l for marine life. The NAS/NAE 1972 Water Quality Criteria recommendations are essentially identical to these EPA 1976 Water Quality Criteria. Toxic mercury concentrations range from 0.06 to 1b µg/l (108,122).
Nickel	The 96-hour LC_{50} is 260 gNi^{++}/l for the stickelback. Data indicates that nickel concentrations greater than 100 µg/l may adversely affect several aquatic species. Nickel is very toxic to many plants especially citrus fruits; at concentrations above 0.0005 µg/l it will inhibit plant growth (154).
Selenium	One microgram selenium per liter in drinking water for just 8 hours one time killed 50 percent of Guinea pigs within 30 days (108).

(continued)

TABLE 95. (continued)

	Comments
Silver	In marine teleosts, 0.12 µg/l silver caused significant respiratory depression (154), and 0.1 µg/l reduces the heterotrophic activity of bacteria (109). Sea urchins, Echinoidea sp., suffered delayed development and deformation at 2 g/l silver (154). Five µg/l is toxic to the stickelback, Gasterosteidae (43,154). The ca. 48 hour LC_{50} for the American oyster, Grassostrea virginica, eggs and adults 6 µg/l while these animals suffered 100 percent mortality at 10 µg/l. Rainbow trout, Salmo gairdneri, showed 94 percent mortality in recently hatched fry and retarded growth and development (154). The LC_{50} forthe mayfly, Ephemerella grandis, is less than 1 g/l (108) while the TL_{50} for the stonefly is 4-9 µg/l (108).
Sulfur	The exact form of the sulfur in the waste streams is not known. Hydrogen sulfide is toxic to bullgills at concentrations of 1 µg/l. The 96 hour LC_{50} for northern pike, Esox lucius, is 17 to 32 µg/l (43).
Zinc	Tadpoles suffered stunted growth and showed no evidence of limb buds when exposed to 5.4 µg zinc/l (108). Levels of 6.5 µg/l zinc stimulate the growth of microflora, Chlorella pyrenoidosa (112). Levels of 10 to 100 µg/l zinc is toxic to grass shrimp, Daphnia magna (112); chinook salmon, (112); rainbow trout, Salmo gairdeneri (43), unicellular green algae, Selanastrum capricornatum (108); marine algae, Skeletonema costatum (108), and minnows, Phioxinus phoxinus (108).
pH	In general, pH levels below 5 cause severe changes in communities of microdecomposers, algae, aquatic microphytes, zooplankton, and benthos.. The grass shrimp, Daphnia pulex does not reproduce successfully below pH 7.0, but it can tolerate a pH as low as 4.3 (112). No snails were found in 832 lakes at pH values less than 5.2; snails were rare in the range pH 5.2-5.8 and occurred less frequently in the pH range 5.8-6.6 than in more neutral or alkaline water (108). Many fish species including small mouth, Micropterus dolomieui, walleye, Stizostedion vitreum; and burbot, Lota lota (108). A pH range of 6.0 to 8.3 should not be hazardous to livestock.
Suspended solid	The preliminary draft of the EPA Quality Criteria for water indicates that a suspended solid level of 25,000 µg/l will allow fish and wildlife propagation (157).
Phenol	The green algae, Chlorella vulgaris, grew abnormally during chronic exposure to 10 µg/l phenol/l (158). Concentrations of phenol as low as 79 µg/l is reported toxic to some minnows (43). The EPA recommends a level of 1 µg/l to protect against fish flesh tainting.
	See cresol.
	See cresol.

TABLE 96. REGULATED WATER POLLUTANTS FOR WHICH THE PREDICTED ENVIRONMENTAL HAZARD MAY BE TOO LOW

	Present MATE ($\mu g/l$)		Proposed (Ecological) MATE ($\mu g/l$)
Pollutant	Health Based	Ecological Based	
Aluminum	8.0×10^4	1000.	100.
Barium	5000.	2500.	100.
Beryllium	30.	55.	2.5
Cadmium	50.	1.0	0.01
Chloride	1.3×10^6		3.
Chromium	250.	250.	10.
Copper	5000.	50.	1.
Lead	250.	50.	10.
Mercury	10.	250.	0.05
Selenium	50.	25.	0.5
Silver	250.	5.0	0.1
Zinc	2.5×10^4	100.	5.
Phenols	5.	500.	10.

TABLE 97. SAM/IA ANALYSIS OF AQUEOUS EFFLUENT OF THE HYDROTREATING MODULE, PHENOL RECOVERY MODULE, AND BIO-UNIT

	Potential Degree of Hazard					
	Hydrotreating Module		Phenol Recovery Module		Bio-Unit Effluent	
Material	Health Based	Ecological Based	Health Based	Ecological Based	Health Based	Ecological Based
Ammonia	5.2x10^{3*}	2.6x10^{5*}	6400.*	3.2x10^{5}		
Biphenyl					0.0020-0.0073	
Cresols					188.*	1.88*
C_2-Anthracene					1.2x10^{-5}	
C_3-Phenols					18.*	0.18
Dimethylnaphthalene					1.5x32.9x10^{5}	
Fluoranthene					4.3-45.x10^{-5}	
Hydrocarbon (as ethane)			0.0073			
Hydrogen sulfide	510.*	1.2x10^{6*}	520.*	1.2x10^{6*}		
1-Isopropylnaphthalene					9.4-32.9x10^{-5}	
2-Isopropylnaphthalene					3.2-11.5x10^{-5}	
Naphthalene					0.0011	8.1*
Naphthols (α-, β-, methyl-)					60.*-580*	0.6-5.8*
Phenol			2.4x10^{4*}	240.*	78.*	0.78
Phenanthrene/anthracene					0.010	
Pyrene					6.9x10^{-5}	
Xylenol					76.*	0.76
Tetralin					2.5x10^{-5}	0.05
Quinoline						
Methylquinoline						
Dimethylquinoline					0.0-0.4	
Ethylquinoline						
Benzoquinoline						
Methylbenzoquinoline					0.0-0.12	
Tetrahydroquinoline					0.0-0.65	
Isoquinoline					0.0-0.65	
Indole						
Metylindole					0.0-0.16	
Dimethylindole						
Benzoindole						
Methylbenzoindole						
Stream flow rate (1/sec) Q =	9.2	9.2	0.0347	0.0347	36.6	36.6
Stream degree of hazard:	5700	1.4x10^{6}	3.1x10^{4}	1.5x10^{6}	420-940	13-18
No. of entries compared to MATEs	2	2	4	3	19	7
Toxic unit discharge sum:	5.2x10^{4}	1.8x10^{7}	1.1x10^{3}	5.3x10^{4}	1.5(3.4)x10^{4}	480-660

*A potential degree of hazard greater than one (1) indicates that this component may represent a significant environmental hazard

TABLE 98. SAM/IA ANALYSIS OF AQUEOUS EFFLUENT FROM COAL PILE DRAINAGE, ASH POND EFFLUENT, AND WASTEWATER

	Potential Degree of Hazard				
	Coal Pile Drainage[a]		Ash Pond Effluent	Wastewater[a]	
Material	Health Based	Ecological Based	Health Based	Health Based	Ecological Based
Aluminum	9.1*(15.*)	730.*(1200.*)	0.021-0.025	0.0031(0.0042)	0.25(0.34)
Ammonia	0.038(0.098)	2.0*(5.1*)			
Arsenic	0.0014(0.0014)	0.20(0.20)	0.020-0.048	0.0013(0.0044)	0.0066(0.022)
Antimony				$4.4x10^{-7}(2.7x10^{-4})$	$1.6x10^{-5}$(<0.1)
Barium	0.04(0.04)	0.20(0.20)	0.040	0.025(0.050)	0.052(0.10)
Beryllium	0.33(0.33)	0.18(0.18)	0.33		
Bismuth				5.2*	
Cadmium	0.080(0.12)	4.0*(6.0*)	0.02		
Calcium	1.2*(1.5*)	19.*(22.*)	0.363-0.479	0.35(0.74)	5.3*(12.*)
Cerium				$5.3(7.2)x10^{-9}$	
Cesium				$4.3(7.2)x10^{-6}$	
Chloride	0.077(0.37)			0.0050(0.0085)	
Chromium	8.*(63.*)	8.*(63.*)	0.084-0.172	0.36(0.88)	0.36(0.88)
Cobalt				$2.3(540.)x10^{-6}$	6.8(1640)x10
Copper	0.30(0.68)	30.*(68.*)	0.04-0.10	0.0022(0.0060)	0.22(0.60)
Gallium				$3.5(5.7)x10^{-5}$	
Hafnium				$2.9(4.3)x10^{-10}$	
Iron	6000.*(6200.*)	$36000.*(3.7x10^{5})$	0.153-0.160.	0.37(0.83)	2.2*(5.0*)
Lanthanum				$3.9(5.9)x10^{-11}$	
Lead	0.064(3300.*)	$0.32(1.7x10^{4*})$	0.040-0.10		
Magnesium	0.72(1.9*)	0.75(2.0*)	0.011-0.022	0.020(0.050)	0.21(0.05)
Manganese	272.*(440.*)	680.*(1100.*)	0.040	0.080(0.31)	0.20(0.77)
Mercury	1.4*(2.7*)	0.056(0.11)	0.040-3.8	0.39(1.9*)	0.016(0.076)
Nickel	4.3*(7.4*)	100.*(170.*)	0.217-0.304	$6.5x10^{-5}(0.056)$	0.0015(1.3*)
Phosphorus	0.048(0.080)	1440.*(2400.*)			
Potassium				0.050(0.11)	0.065(0.14)
Rubidium				$1.4(4.9)x10^{-9}$	
Samarium				$9.0(15.2)x10^{-11}$	
Scandium				$1.6(125.)x10^{-10}$	
Selenium	0.40(0.60)	0.80(1.2*)	0.22-0.32	0.16(0.040)	0.032(0.084)
Silicon	0.61(0.61)				
Silver			0.04		
Sodium	0.84(1.6*)			0.15(0.76)	
Strontium				$7.4(15.9)x10^{-4}$	
Sulfide	170.*(170.*)	5800.*(5800.*)			
Tantalum				$2.9(4.0)x10^{-9}$	
Thorium				$1.9(4.0)x10^{-8}$	
Titanium	0.01(0.01)	3.7*(3.7*)		0.0013(0.0030)	0.44(1.0*)
Vanadium				$4.8(9.6)x10^{-4}$	0.0080(0.016)
Zinc	0.20(0.92)	51.*(230.*)	0.001-0.002	$1.6x10^{-6}$	$4.0x10^{-4}$
Zirconium				$3.3(6.4)x10^{-4}$	
Stream flow rate (1/sec) Q =	ca.1.0	ca.1.0	Not estimated	36.6	36.6
Stream degree of hazard =	6500.(66000.)	$4.5(40)x10^{4}$	1.7-6.0	7.1-11.	9.3-22.
No. of entries compared to MATEs	24	20	17	34	19
Toxic unit discharge sum	ca.6500(ca.66000)	$ca.4.5(40)x10^{4}$		260.-400.	340.-800.

*A potential degree of hazard greater than one (1) indicates that this component may represent an environmental hazard.

[a] Numbers in parenthesis based on maximum, other numbers based on average.

5.3.4 Evaluation of Unregulated Pollutants and Bioassay Results

Table 99 shows two pollutants for which standards do not exist. The SAM/IA analysis indicates that these two pollutants may cause problems in the coal pile drainage. No other unregulated pollutants have been projected to represent an environmental hazard.

The use of bioassays for the prediction of ecological and health hazards of various effluents to the environment from the SRC main unit operations and auxiliary processes is underway, as reported in Section 3.0. Bioassay results reported to date, however, are limited to studies of the toxicity to fish of acid and neutral leachates from the SRC-mineral residue from Kentucky No. 9 coal. Both the undiluted acidic (pH 5.6) and neutral leachates of SRC-mineral residue caused the death of one to six day-old fathead minnows during 96-hour exposures. Survival was ensured only with a 1:10 dilution of either leachate (42). From these data it was not possible to determine which inorganic constituent(s) caused fish death; however, toxic levels of Al, Cr, Cu, Ni and Zn were present in the acid leachate (42).

5.4 Impacts of Land Disposal

5.4.1 Summary of Final Land Disposal Standards

5.4.1.1 Federal Regulations

On February 1, 1978 the U.S. Environmental Protection Agency promulgated, under Section 3006a, Subtitle C of the Solid Waste Disposal Act as amended by the Resource Conservation and Recovery Act (RCRA) of 1976, a set of guidelines for State hazardous waste management programs. Hazardous wastes were found by the U.S. Congress to present special

TABLE 99. AMOUNT AND HAZARD EXPECTED FROM UNREGULATED POLLUTANTS

Pollutant	Coal Pile Drainage (μg/l)	Wastewater (μg/l)	Appropriate MATE (μg/l)		Comments
			Health Based	Ecological Based	
Phosphorus	720.		$1.5x10^4$	0.5	Phosphate is not directly toxic to man or to aquatic organisms. It is an essential nutrient and may affect water quality by enhancing the rate of eutrophication.
Silicon	$9.1x10^4$		$1.5x10^5$		Levels of 500 μg/l stimulate the growth of the alga, Asterionella sp. (109). If this is a general effect, this silicon concentra- could lead to entrophication.
Naphthols		300-2900	5.0	500.	β-naphthol is carcinogenic.

dangers to health; therefore, the states must develop programs to control them. In the event that any state chooses not to develop such a program, the EPA is required to do so. Hazardous wastes that are judged to have a significant impact on human health and the environment will be defined by the Section 3001. These final regulations were to have been issued by April 1978 along with criteria and methods for identifying and listing hazardous wastes. As a result of delays, EPA is an estimated six months behind schedule in issuing standards for what constitutes a hazardous waste (128). Once EPA criteria are established those wastes identified by such means are then to be included in the management control system constructed under Sections 3002 through 3006, and 3010 of the RCRA guidelines. The effective date for the regulations promulgated under Sections 3001 to 3005 was stated as October 21, 1978. The 6-month time period after final promulgation will be used to increase public understanding of the regulations, and to allow compliance by those covered by the regulations. During this same period, notifications required under Section 3010 may be submitted, and facility permit applications required under Section 3005 may be distributed for completion by applicants.

Section 3002 of the regulations presents the standards applicable to classes of generators of hazardous wastes and requires the creation of a manifest system for tracking wastes from the generation point to the final site of storage, treatment or disposal facility to which a permit was issued. Thus, the "cradle-to-the-grave" concept on which Subtitle C is based, includes the requirement that the regulatory agency has knowledge of the existence and movement of hazardous wastes through their entire life cycle. Those few states which already have a manifest system may be required to make it consistent with the federal system. The EPA expects to provide assistance to the states (i.e., software and other tools) in setting up the new manifest system.

Section 3003 addresses standards applicable to transporters of hazardous wastes relative to management of such wastes during the transport phase. Section 3004 addresses standards affecting owners and operators of hazardous waste storage, treatment, and disposal facilities. These standards provide the criteria against which EPA (or state) officials will review permit applications for on-site as well as off-site facilities operated by a generator or transporter of wastes. Generators and transporters who do not treat, store, or dispose of hazardous wastes do not need permits.

Section 3005 regulations define the scope, coverage, and requirements for permit application as well as for the issuance and revocation of permits. Any possible overlaps between the state's issuance of permits to hazardous waste injection wells, and the issuance of hazardous waste permits under a state's existing program will be resolved by EPA.

Section 3010 requires that any person generating, transporting, owning, or operating a facility for storage, treatment and disposal of hazardous wastes must notify the EPA of a state of this activity within 90 days of the EPA promulgation of regulations defining a hazardous waste (Section 3001).

Any state already having promulgated other legislation, which, in the opinion of the state and of the EPA is sufficient to allow the enforcement of a state hazardous waste program equivalent to that of the EPA, will be considered to satisfy the hazardous waste guidelines proposed by EPA.

5.4.1.2 State Regulations

Requirements promulgated by the EPA for state hazardous waste management programs were discussed earlier in this section. Seventeen coal-producing states have issued stipulations for some form of hazardous and solid waste management, as shown in Table 100. Thus, among the 17 coal-producing states listed, 14 have provided some type of statutory control over hazardous waste disposal operations. Among these states, Ohio, North Dakota and Utah have explicit monitoring requirements for types of waste disposal operations. In view of the fact that the potentially vast amounts of solid wastes produced by coal conversion technologies, through compliance with air quality standards, must be disposed of on land, it is apparent that there is an equally vast potential for the degradation of local surface and groundwater systems near these disposal sites by the inorganic and organic leachates.

5.4.1.2.1 EPA Region III (Pennsylvania and West Virginia

The solid waste legislation of Pennsylvania is among the most extensive of any of the states considered. In addition to the general solid waste legislation, Pennsylvania has promulgated rules and regulations governing coal refuse disposal. These rules may be more indicative of future legislation regarding SRC generated residue. The rules are general, prohibiting disposal which will promote fire, subsidence, or leaching problems. The state also has published a statement of guidelines and acceptable procedures for the operation of such disposal areas. Generally, two feet of final cover are required. The landfill shall be a minimum of six feet above the seasonal high water table.

TABLE 100. EXISTING STATE REQUIREMENTS FOR HAZARDOUS AND SOLID WASTES

EPA Region and States		Hazardous Waste Controls	Permit Requirement	Approval	Design Criteria and Standards	Monitoring Requirements
III	Pennsylvania	yes	yes	no	yes	no
	West Virginia	yes	yes	no	yes	no
IV	Kentucky	yes	yes	no	yes	no
V	Illinois	yes	yes	no	yes	no
	Indiana	yes	yes	no	no	no
	Ohio	yes	yes	no	yes	yes
VI	New Mexico	no	yes	no	yes	no
	Texas	yes	yes	manifest	yes	no
VIII	Colorado	yes	yes	no	yes	no
	Montana	yes	no	notice	yes	no
	North Dakota	yes	yes	no	yes	yes
	Utah	yes	no	yes	no	yes
	Wyoming	yes	no	yes	yes	yes
IX	Arizona	yes	no	yes	no	no
X	Alaska	no	yes	no	no	no

Disposal cells may not exceed eight feet with compacted solid waste layers of two feet or less. Hazardous waste disposal plans must be approved by the appropriate state agencies.

West Virginia has three solid waste disposal class ratings:

- Class I (wastes having a hazardous nature or water soluble substances having toxic or infectious properties or special water pollution potential which must be kept away from useable water sources regardless of costs)
- Class II (decomposable organic materials;
- Class III (inert and relatively nondecomposable materials presenting only confinement and esthetic problems. The mineral residue wastes from the SRC process would be considered under the Class I category, for which the disposal requirements are determined separately for each application.

5.4.1.2.2 EPA Region IV (Kentucky)

Kentucky solid waste requirements include providing more than two feet of compacted soil between solid waste and maximum water table, two feet or more of compacted earth between solid waste and bedrock, solid waste layers of two to three feet and a final daily cover of six inches to prevent waste dispersion. A final cover of two feet of compacted soil is required to be followed by revegetation.

5.4.1.2.3 Region V (Illinois, Indiana and Ohio)

The Illinois EPA (IEPA) stated in Rule 310(b) of the Solid Waste Rules and Regulations (Chapter 7 of the Environmental Protection Act) that hazardous wastes or liquid wastes and sludges may be accepted at a sanitary landfill only if authorized by permit. Thus, the IEPA can issue a supplemental permit allowing sanitary landfills to deviate from the applicable rules.

The IEPA requires that the applicant for a supplemental permit must submit information on the following (129):

- Type, consistency and physical/chemical properties of the special or hazardous wastes
- Quantity
- Method of disposal.

The IEPA stipulates procedures for analysis of specific inorganics and organics, by use of their landfill simulation leaching test. All known organic components of the waste should be determined if their concentrations exceed 0.1 percent (1000 ppm) of the total waste volume. Table 101 lists the minimum number of inorganics (130), organics (94), and radioactivity (alpha emitters) to be assayed. The assumption is made that the waste generator is aware of his usage of beryllium, selenium, antimony or other potentially hazardous chemicals, and that the waste will be analyzed for components used in the process by which the waste originates. The analysis numbers in Table 101 refer to the industry classification by IEPA in which thousands of standard industrial classification (SIC) numbers were condensed into nine categories composed of 46 subgroups (129).

TABLE 101. ANALYSIS CHART FOR WASTE GROUPS (136)

WASTE GROUP	ANALYSIS NUMBER	PARAMETER										
		Arsenic	Cadmium	Chromium[a]	Copper	Cyanide[b]	Lead	Mercury	Nickel	Phenols	Zinc	Alpha Radiation[c]
Metals	1.01		X	X	X	X	X	X	X	X	X	X
	1.02		X	X	X	X	X		X		X	
	1.03		X	X	X	X	X		X		X	
Chemicals	2.01		X	X	X	X	X	X	X	X	X	
	2.02	X	X	X	X	X	X	X	X		X	X
Chemical Specialties	3.01-3.06	X	X	X	X	X	X	X	X	X	X	
Food	4.01-4.06											
General Manufacture	5.01-5.11	X	X	X	X	X	X	X	X	X	X	
Mining	6.01-6.04	X	X	X	X		X	X	X		X	X
Service Industries	7.01		X	X	X		X		X		X	
	7.02	X			X			X				
	7.03	X				X				X		X
	7.04-7.06		X	X			X	X	X			
Utilities	8.01, 8.05		X	X	X		X	X	X		X	
	8.02											
	8.03											X
	8.04	X	X	X	X	X	X	X	X		X	X
Wholesale, Retail Trade	9.01-9.03		X	X	X		X	X	X	X	X	

[a] Total soluble chromium

[b] "Free" cyanide per modified Leibeg method (ASTM)

[c] Measured from waste as received (unfiltered) in pCi/l

Note: As more data become available, it is likely that this analysis chart will be expanded in terms of minimum required parameters and lengthened relative to industry specific analyses.

The IEPA has specified absolute permissible maximum water soluble waste chemical concentrations for disposal at either of Types I, II or III disposal sites, as follows (129):

Soluble Inorganics[a]	Type of Disposal Site, and Limiting Concentration (ppm) Type I	Type II	Type III
As	500	75	25
Cd	500	75	25
Cr[b]	1,000	150	50
CN[c]	500	75	25
Cu	1,000	150	50
Hg	500	75	25
Ni	500	150	50
Pb	500	150	50

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[a] Where soluble concentrations exceed limitations, a waste may receive pretreatment to insolubilize excess concentrations.

[b] Total soluble Cr.

[c] Total soluble cyanide (CN^-).

The Type I site will receive waste displaying a high ingestion toxicity (based on the Sax rating), and thus "very hazardous." The criteria for the Type I site require that it be buffered by at least 3.04 meters of soil having a coefficient of permeability not greater than 1 x 10^{-8} cm/sec, or not less than 3.04 meters of soil which can provide contaminant for 500 years (129). The Type II site must provide a containment life for less hazardous substances of 250 years. The Type III site must provide a containment life for municipal refuse of 100 years. Liquid special wastes may be placed onto any of the three site types if the liquid is subjected to vertical and horizontal containment. Acceptable methods for disposing toxic and hazardous wastes in Illinois are shown in Table 102.

TABLE 102. IEPA ACCEPTABLE DISPOSAL METHODS (136)

Waste Property	Type of Site			Disposal Method[a]			
	I	II	III	A	B	C	D
Highly Acidic	-	-	-	-	-	-	-
Moderately Acidic	-	-	-	-	-	-	-
Low Acidity	X[b]	X	X	X	X	X	X
Highly Alkaline	X	X	X	-	X	X	X
Moderately Alkaline	X	X	X	X	X	X	X
Low Alkalinity	X	X	X	X	X	X	X
High Volatility	X	X	-	-	X	X	X
Moderate Volatility	X	X	-	-	X	X	X
Low Volatility	X	X	X	X	X	X	X
High Toxicity (dermal)	X	X	-	-	X	X	X
Moderate Toxicity (dermal)	X	X	-	X	X	X	X
Low Toxicity (dermal)	X	X	X	X	X	X	X
High Toxicity (Inhalation)	X	X	-	-	X	X	X
Moderate Toxicity (Inhalation)	X	X	-	X	X	X	X
Low Toxicity (Inhalation)	X	X	X	X	X	X	X
High Toxicity (Oral)	X	-	-	X	X	X	X
Moderate Toxicity (Oral)	X	X	-	X	X	X	X
Low Toxicity (Oral)	X	X	X	X	X	X	X
Radioactive	-	-	-	-	-	-	-
Reactive	X	X	-	-	-	-	X
Explosive	-	-	-	-	-	-	-

[a] Note: A=Direct Landfill; B=Subsurface Injection; C=Surface Adsorption; D=Consignment Burial

[b] X - Indicates permittable disposal site or method of disposal.

In Indiana, prior to the issuing of permits to operate landfills, a detailed plan of the operation must be submitted to and approved by the appropriate state agencies. Hazardous wastes shall not be accepted at a sanitary landfill unless authorized by the Indiana Stream Pollution Control Board.

The state of Ohio defines hazardous wastes as those substances which singly, or in combination, pose a significant present or potential threat or hazard to human health or to the environment, because of the following factors:

- Flammability
- Explosiveness
- Reactivity
- Corrosiveness
- Toxicity
- Infectiousness
- Carcinogenicity
- Bioconcentrative potential
- Persistence in multimedia environment
- Potential lethality
- Acts as an irritant or sensitizer.

Under the requirements promulgated by the Ohio Department of Health for sanitary landfill operations, there is an explicit requirement that the operator "shall install such a number of monitor wells...as the Health Comissioner deems necessary to determine the effect of the facility upon the quality of groundwater" (131). Each monitor well(s) shall be sampled semi-annually for chlorides, COD, TOC, TDS, and methylene blue active substances. More frequent sampling and sampling for additional substances may be required if a substantial threat of water pollution exists. Specific instructions were issued concerning the eventual detection of leachate on the disposal site. Hazardous waste cannot be accepted at sanitary landfills. The monitoring wells must be maintained by the operator for three years after closure.

5.4.1.2.4 EPA Region VI (New Mexico and Texas)

Solid waste regulations in New Mexico are not as advanced or as complicated as their standards for air and water controls. State requirements include six inches of daily cover, compaction of wastes to smallest practical volume and a minimum final cover of two feet of earth. Landfill bottoms must be a minimum of twenty-feet above groundwater level.

5.4.1.2.5 EPA Region VIII (Montana, North Dakota, South Dakota, Utah, and Wyoming)

Colorado's solid waste requirements are general and not very vigorous. Compaction of wastes is required.

In Montana site approval is required for solid waste disposal when hazardous wastes are involved. A daily cover of six inches and a final cover of two feet or more are also required. Disposal sites shall not be located near springs or other water supplies, near geologic formations which could cause leaching problems, in areas of high groundwater tables or within the boundaries of 100-year flood plains.

In North Dakota, the Department of Health may impose any reasonable conditions upon a permit to construct a land disposal site, including the following:

- Sampling, testing and monitoring facilities.
- Trial operation and performance testing.

North Dakota has stipulated standards of performance for the following types of disposal operations:

- Sanitary landfills
- Construction and demolition disposal sites
- Incinerators
- New and unique methods of disposal
- Hazardous wastes.

The monitoring standards presently apply to sanitary landfills, and sites handling construction and demolition wastes.

The standards for disposal of hazardous wastes shall be met by the owner of such wastes. However, the state may provide technical assistance to the owner for the storage, transportation and disposal of hazardous wastes. North Dakota defines hazardous wastes as those substances which singly, or in combination, exhibit a substantial present or potential hazard to human or living organisms because of the following factors:

- Nondegradability
- Persistence in multimedia context
- Biomagnification potential
- Lethality
- Shown to produce detrimental cumulative health and ecological effects.

South Dakota solid waste regulations have requirements pertaining to site locations. Landfills are not permitted within 1,000 feet of any lake or pond, or within 300 feet of any stream or river. Also, a minimum of six feet between waste and the groundwater table must be preserved. Such requirements, promulgated specifically to prevent leaching to groundwater, may provide an applicable basis for future regulatory control of disposal of SRC solid wastes.

In Utah all solid waste disposal operations must meet with the approval of the Utah State Division of Health. Approval for disposal of hazardous wastes will depend upon the following:

- Location of hazardous waste disposal area

- Consideration of pertinent geological data
- Responsible control of hazardous waste disposal sites
- Installation of adequate fencing, gates, and signs to enclose the hazardous waste disposal area
- Precautions to protect all surface and groundwaters.

The Wyoming Department of Environmental Quality reviews construction and operating plans of all industrial or hazardous waste disposal operations. Industrial waste disposal sites shall not be located in areas of low population density, land use value and groundwater leaching potential. Monitoring wells must be installed prior to commencement of operations. Disposal sites may not be located near drinking water supply sources. It is suggested, but not required, that disposal sites with impermeable soil be selected.

5.4.1.2.6 EPA Region IX (Arizona)

Arizona solid waste legislation lags behind air and water legislations. Daily landfill covers of six to twelve inches are required. The final cover must be a minimum of two feet deep.

5.4.1.2.7 EPA Region X (Alaska)

Alaska regulations for the management of solid wastes are directed primarily towards municipal wastes rather than industrial. Should leaching or permafrost prove a problem, special disposal procedures must be submitted to the Department of Environmental Conservation. A minimum of two feet of earth must be maintained between solid wastes and the anticipated high groundwater table. Surface drainage must be prevented from coming into contact with the landfill area. Solid waste may be landfilled in layers of not more than two feet prior to compaction.

5.4.2 Comparison of Waste Streams with Dipsosal Standards

Flows of solid wastes from applicable basic unit operations and auxiliary processes are shown in Figure 64. Accompanying this chart is a tabular summary and a narrative summary that attempts to identify, and where feasible to quantify those hazardous wastes which may be destined for land disposal. In Section 5.4.3, comparisons are made of certain unregulated pollutants associated with hazardous wastes from seven auxiliary processes whose levels may cause ecological and/or human health problems. In Section 5.4.2, no comparisons of regulated pollutants were made, since no SRC-specific land disposal standards were found.

5.4.2.1 Potential Hazardous Wastes from Basic Unit Operations

The six main unit operations are shown along the right side of Figure 64. Vertical (downward) arrows trace the flows of known solid wastes from the applicable processes. Throughout this discussion, it is assumed that most of the solid wastes generated will be disposed of by landfilling in appropriate areas, as advocated in an earlier report (6). With reference to the hazardous nature of several SRC solid wastes, the following precautions should be considered prior to disposal:

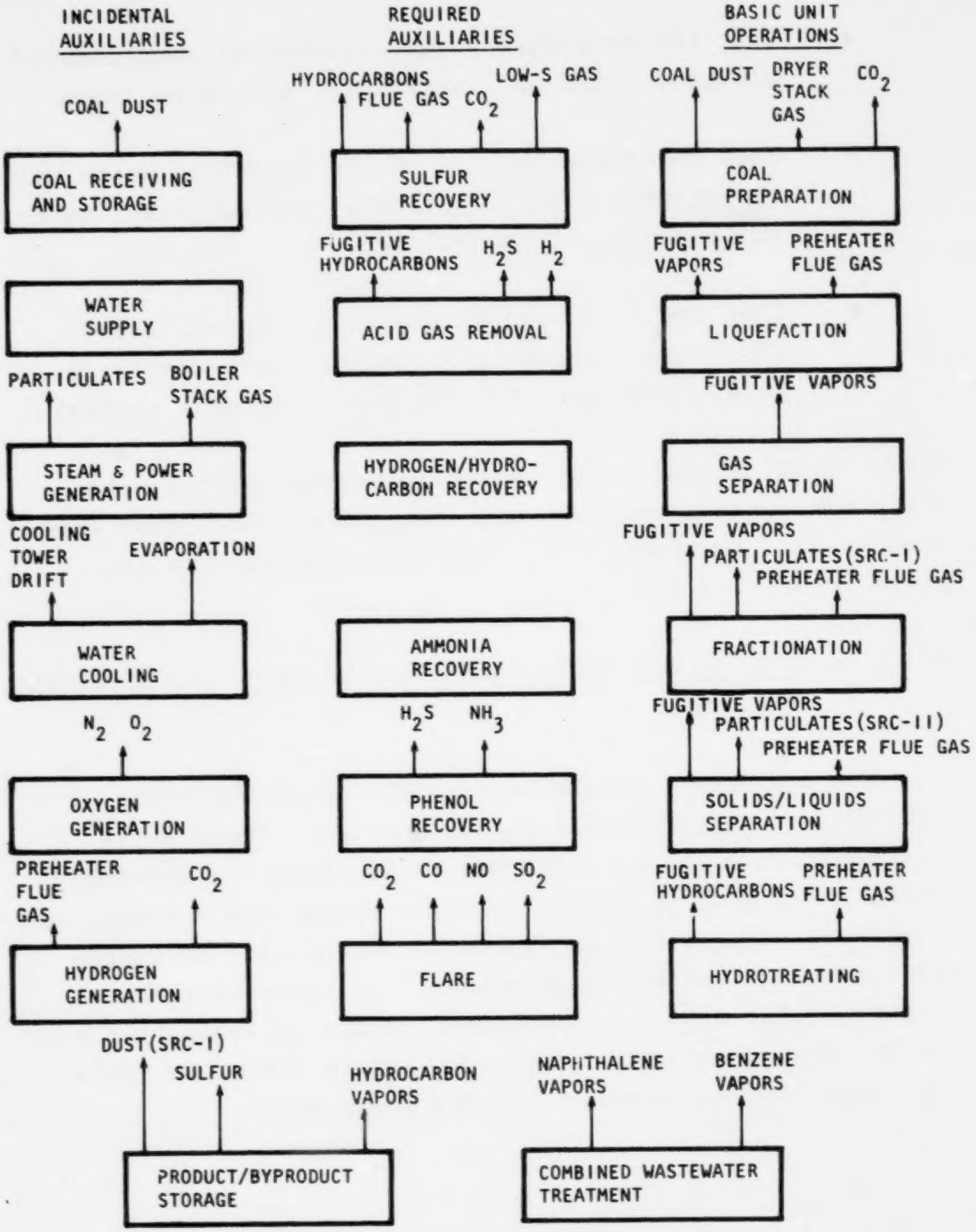

INCIDENTAL AUXILIARIES
REQUIRED AUXILIARIES
BASIC UNIT OPERATIONS
COAL DUST
COAL RECEIVING AND STORAGE
WATER SUPPLY
PARTICULATES
BOILER STACK GAS
STEAM & POWER GENERATION
COOLING TOWER DRIFT
EVAPORATION
WATER COOLING
N2 O2
OXYGEN GENERATION
PREHEATER FLUE GAS
CO2
HYDROGEN GENERATION
HYDROCARBONS
FLUE GAS
CO2
LOW-S GAS
SULFUR RECOVERY
FUGITIVE HYDROCARBONS
H2S
H2
ACID GAS REMOVAL
HYDROGEN/HYDRO-CARBON RECOVERY
AMMONIA RECOVERY
H2S
NH3
PHENOL RECOVERY
CO2
CO
NO
SO2
FLARE
COAL DUST
DRYER STACK GAS
CO2
COAL PREPARATION
FUGITIVE VAPORS
PREHEATER FLUE GAS
LIQUEFACTION
FUGITIVE VAPORS
GAS SEPARATION
FUGITIVE VAPORS
PARTICULATES(SRC-I)
PREHEATER FLUE GAS
FRACTIONATION
FUGITIVE VAPORS
PARTICULATES(SRC-II)
PREHEATER FLUE GAS
SOLIDS/LIQUIDS SEPARATION
FUGITIVE HYDROCARBONS
PREHEATER FLUE GAS
HYDROTREATING
DUST(SRC-I)
SULFUR
HYDROCARBON VAPORS
PRODUCT/BYPRODUCT STORAGE
NAPHTHALENE VAPORS
BENZENE VAPORS
COMBINED WASTEWATER TREATMENT

Figure 64. Potential solid wastes from basic unit operations

- That the solids, singly or in-mixture, should receive chemical stabilization.

- That the potential physical/chemical reactions of sludges, singly or in-mixture, should be known.

- That the compatibility of the hazardous waste with appropriate liners, sealants, and container materials should be established.

- That the life span of the land disposal site should meet the most stringent state standards, (via., 500 years for the most hazardous wastes).

Those fugitive emissions from solid wastes which escape pollution control measures have been considered under emission to air, Section 5.2.2. Characterization data are given in Section 3.0.

5.4.3 Evaluation of Unregulated Pollutants and Bioassay Results

The components of the solid waste which may cause problems are listed in Tables 103 and 104. These solid pollutants were judged to be hazardous using the MEG-SAM/IA method. For some pollutant species, documented evidence was found suggesting possible environmental hazards at concentrations below current MATE values. In those instances, proposed MATEs have been developed, based on evaluation of the documented evidence. These MATEs are listed in Table 105 along with recommendations for lower MATEs.

TABLE 103. UNREGULATED SOLID WASTES WHICH MAY CAUSE ENVIRONMENTAL HAZARDS

Pollutant	SRC-Mineral Residue (μg/g) [Avg.(max.)]	API Separator Bottoms (μg/g)	Biosludge (μg/g) [Avg.(max.)]	Fly Ash (μg/g) [Avg.max.]	Bottom Ash (μg/g)	Flare K.O. Drum (μg/g)	Gasifier Slag (μg/g)	Applicable MATE (μg/g)		Comment
								Health Based MATE	Ecological Based MATE	
Aluminum	$5.9(8.1)\times10^4$		$1.8(2.5)\times10^4$	$7.9(11.)\times10^4$				1.6×10^4	200.	High concentrations of aluminum in soils with low pH causes restricted root growth in plants (43)
Arsenic	56.(180)	1.0		120.(385.)	30.	1.4(4.6)	24.(130.)	50.	10.	The amounts of arsenic (primarily in its arsenate form) producing toxicity in sensitive plants vary from 110-340 kg/hectare for sandy to clayey soils respectively (43).
Boron	1200.(2470.)		115.(230)	2500.(5000.)	1400.	48.(95.)		1000.	500.	
Beryllium	7.(15.)	4.8		11.(24.)	2.1			6.	11.	
Boron	250.(550.)	7.2		385.(3000.)	300.			9300.*	5000.*	Fruit trees require 0.5 to 1.0 μg/g boron for growth while 2.0 μg/g is possibly toxic. Oats, radishes and clover show abnormal growth at more than 3.0 μg/g boron (43,109).
Cadmium	6.2(29.)	0.5		71.(340.)	40.			10.	0.20	The recommendation of the U.S. Department of Agriculture and Land Grant Colleges is a concentration of cadmium of 10 kg cadmium/hectare for most soils (43).
Calcium	$1.1(2.3)\times10^5$		$2.3(5.1)\times10^4$	$3.2(7.1)\times10^4$			$1.3(2.9)\times10^4$	4.8×10^4	3200.	
Chromium	120.(290.)	125.		150.(500.)	170.	15.(35)	34.(83.)	50.*	50.*	Chromium concentrations of 10 μg/g in soil culture reduced soybean yield (43).
Cobalt	44(110.)			100.(250.)		$2.6(6.2)\times10^{-3}$		150.	50.	

(continued)

TABLE 103. (continued)

Pollutant	SRC-Mineral Residue (µg/g) [Avg.(max.)]	API Separator Bottoms (µg/g)	Biosludge (µg/g) [Avg.(max.)]	Fly Ash (µg/g) [Avg.max.]	Bottom Ash (µg/g)	Flare K.O. Drum (µg/g)	Gasifier Slag (µg/g)	Applicable MATE (µg/g) Health Based MATE	Applicable MATE (µg/g) Ecological Based MATE	Comment
Copper	83.(220.)	3500.	91.(240.)	100.(400.)	170.		32.(84.)	1000.*	10.	Chlorosis, or drying of leaves, was observed in guar Cyamopsis psoraboides; bottle gourd, Lagenaria levcantha; eggplant, Solanum melonsena; and blue panic grass, Panicum antidotale Retz, grown in soil containing 0.001, 0.01, 0.10, 1.00 and 10.00 µg/g copper for 70 days. Deficiency symptoms may occur in plants at less than 5 ppm copper in soil. At soil concentrations above 20 ppm, toxic symptoms may occur (43). The U.S. Department of Agriculture and Land Grant Institution recommended a concentration of 250 kg/hectare (43).
Fluorine				ca.130.(345.)	$1.1x10^4$			7500.		
Iron	$4.2(20)x10^5$	5560.		$7.4(16.)x10^4$		3400. (7600)	3.7(8.25) $x10^4$	300.	50.	
Lead	68.(340.)	182.		130.(650.)	180.		20.(100.)	50.	10.	The U.S. Department of Agriculture and Land Grant Institutions recommend a concentration of 1,000 kg lead/ha (43).
Lithium				300.(670.)				70.	75.	
Manganese	240.(920.)		21.(80.)	250.(970.)	120.		97.(0370.)	50.*	20.*	Soil concentrations of 2.5 µg/g have caused this effects soybeans; soil effects, however, depend on a variety of factors such as pH and moisture (43).
Molybdenum	22.(50.)			120(350.)	34.			$1.5x10^{4*}$	1400.*	Molybdosis of cattle is associated with alsike clover grown in soils that had 10 to 100 ug/l of molybdenum in saturation extracts (MEG.) A molybdenum dietary concentration of 5 to 10 µg/g is considered toxic to cattle (43).

(continued)

TABLE 103. (continued)

Pollutant	SRC-Mineral Residue (μg/g) [Avg.(max.)]	API Separator Bottoms (μg/g)	Biosludge (μg/g) [Avg.(max.)]	Fly Ash (μg/g) [Avg.max.]	Bottom Ash (μg/g)	Flare K.O. Drum (ug/g)	Gasifier Slag (μg/g)	Applicable MATE (μg/g) Health Based MATE	Applicable MATE (μg/g) Ecological Based MATE	Comment
Nickel	95.(600.)	23.		130(920)	87.	13.(80.)	42.(270.)	45.	2.0	
Phosphorous				1000.(3200)				3000.	0.1	
Potassium	$1.8(4.0)\times10^4$			$1.6(3.6)\times10^4$		850. (1800.)	4100. (9000.)	6000.		
Selenium	20.(51.)	26.		64.(170.)	0.31	1.3(3.4)	7.2(19.)	10.*	5.*	Since flora concentrate selenium, the concentration of selenium in floral species can be up to 1000 times the concentration in the soil without apparent floral damage; however, these concentrations in flora species can be toxic to foraging animals. A concentration of selenium between 0.04 and 2 μg/g in the diet is required to prevent selenium deficiencies in cattle while concentrations of 4 to 5 μg/g in the diet causes selenium toxicity. Assuming a concentration factor of 1000, flora grown in soil containing 0.004 to 0.005 μg/g selenium would be toxic to foraging animals while soils containing 4.0×10^{-5} to 0.002 ug/g would be deficient. The facts that the dietary concentration of selenium which results in toxicity differ by only a factor of two and that the dietary concentration depends on the flora concentration factor and the soil concentration makes determination of a general soil ambient level goal difficult (43,154).
Silicon				$1.4(3.0)\times10^5$			$3.9(4.8)\times10^4$	3.0×10^4		
Silver				< 3-5				50.	1.0	

(continued)

TABLE 103. (continued)

Pollutant	SRC-Mineral Residue (μg/g) [Avg.(max.)]	API Separator Bottoms (μg/g)	Biosludge (ug/g) [Avg.(max.)]	Fly Ash (μg/g) [Avg.max.]	Bottom Ash (ug/g)	Flare K.O. Drum (μg/g)	Gasifier Slag (μg/g)	Applicable MATE (μg/g) Health Based MATE	Applicable MATE (μg/g) Ecological Based MATE	Comment
Vanadium	150.(300.)		530.(1000.)	310.(600.)	<240.			500.	30.	When present in plant culture solutions at concentrations of 0.5 ug/g or greater, vanadium is toxic to some plants (43).
Zinc	400.(4800.)			1900. (23000.)	<200.		180. (2200.)	5000.	20.	The U.S. Department of Agriculture and Land Grant Institutions recommend a concentration of 500 Kg Zn/hectare for most soils (43).
Naphthalene	1500							1.5×10^5	20.	

TABLE 104. SAM/IA ANALYSIS OF SOLID WASTES FROM THE INORGANIC FRACTION OF THE SOLID RESIDUE, API SEPARATOR BOTTOMS, BIOSLUDGE

	Potential Degree of Hazard					
	Inorganic Fraction of Solid Residue[a]		API Separator Bottoms		Biosludge[a]	
Material	Health Based	Ecological Based	Health Based	Ecological Based	Health Based	Ecological Based
Aluminum	3.7*(5.1*)	295.*(410.*)			1.1*(1.6*)	90.*(120.*)
Antimony	0.0087(0.019)	0.32(0.70)			1.0x10^{-5}	4.0x10^{-4}
Arsenic	1.1*(3.6*)	5.6*(18*)	2.*	10.*	0.0011	0.0057
Barium	1.2*(2.5*)	2.5*(4.9*)			0.12(0.23)	0.23(0.46)
Beryllium	1.2*(2.5*)	0.63(1.4*)	80.*	44.*		
Bismuth						
Boron	0.027(0.059)	0.050(0.11)	0.8	0.14		
Cadmium	0.62(2.9*)	31.*(145.*)	5.*	250.*		
Calcium	2.2*(4.8*)	33.*(72.*)			0.48(1.1*)	7.2*(1.6*)
Cerium	9.1(12.7)x10^{-4}				2.5(3.5)x10^{-5}	
Chlorine	2.7(4.4)x10^{-5}					
Chromium	0.014(0.024)				0.0073(0.012)	
Cobalt	2.4*(5.8*)	2.4*(5.8*)	250.*	250.*	0.0014	0.0014
Copper	0.29(0.73)	0.88(2.2*)			3.3x10^{-5}	1.0x10^{-4}
Dysprosium	0.083(0.22)	8.3*(22.*)	350.*	3.5x10^{4}*	0.091(0.24)	9.1*(24.*)
Fluorine						
Gadolinium						
Gallium	0.0013(0.0021)				8.0(13.3)x10^{-4}	
Germanium						
Hafnium	0.027(0.039)				0.0032(0.0047)	
Holmium						
Indium						
Iron	310.*(670.*)	1840.*(4000.*)				
Lathanum	1.7(2.6)x10^{-4}				8.6(13.2)x10^{-6}	
Lead	1.4*(6.8*)	6.8*(34*)	364.*	1820.*		
Lithium						
Magnesium	0.28(0.72)	0.29(0.75)				
Manganese	4.8*(18.*)	12.*(46.*)			0.42(1.6*)	1.0*(4.0*)
Mercury	0.38(1.8*)	0.015(0.074)	530.*	21.2*	7.0*	0.28
Molybdenum	0.0015(0.0053)	0.016(0.036)				
Neodymium						
Nickel	2.1*(13.*)	48.*(300.*)	51.*	1150.*	4.0x10^{-4}	0.0090
Niobium						
Osmium						
Phosphorus						
Polonium						
Potassium	3.0*(6.7)	3.9*(8.7*)			3.6-10^{-5}	4.8x10^{-5}
Praseodymium						
Rubidium	6.7(23.8)x10^{-4}				3.1x10^{-8}	
Ruthenium						
Samarium	4.6(7.9)x10^{-5}				8.8(14.4)x10^{-6}	
Scandium	1.0(1.7)x10^{-4}				6.9(11.9)x10^{-6}	
Selenium	2.0*(5.1*)	4.0*(10.*)	260.*	520.*	6.9x10^{-4}	0.0014
Silicon						
Silver						
Sodium	0.12(0.61)				2.9x10^{-6}	
Strontium	0.061(0.13)				8.3(17.4)x10^{-4}	
Tantalum	6.7(9.3)x10^{-5}				3.9(5.3)x10^{-6}	
Tellurium						
Thallium	0.012					
Thorium	0.18(0.38)				0.033(0.071)	
Thulium						
Tin						
Titanium	0.083(0.18)	9.4*(21.*)				
Tungsten						
Uranium	0.0012(0.0044)	0.15(0.53)				
Vanadium	0.30(0.60)	5.0*(10.*)			1.1*(2.0*)	18.*(33.*)
Zinc	0.080(0.96)	20.*(240.*)				
Zirconium	0.21(0.41)				0.020(0.038)	

Stream Flow Rate (l/sec) Q = ca. 1.0   ca. 1.0   Not estimated   36.6   36.6

Stream potential degree of hazard: 6500.(6600.)   4.5(40)x10^{4} 1.7-6.0   7.1-11.   9.3-22.

No. of Entries compared to MATEs   24   20   17   34   19

Potential toxic unit discharge rate sum: ca.6500(6600)   ca.4.5(40)x10^{4} 260.-400.   340.-800.

*A potential degree of hazard greater than one (1) indicates that this component may represent an environmental hazard.

[a] **Numbers in parenthesis based on maximum, other numbers based on average, for maximum values followed by an exponential term, the exponential is applicable to both the average and maximum values. Example: Cerium: 9.1 (12.7)x10^{-4} is 9.1x10^{-4}, (12.7x10^{-4}).**

TABLE 105. POLLUTANTS FOR WHICH THE SAM/IA METHOD MAY UNDERESTIMATE THE ENVIRONMENTAL HAZARD

Pollutant	Present MATE ($\mu g/g$) Health Based	Present MATE ($\mu g/g$) Ecological Based	Proposed Land-Based MATE ($\mu g/g$)
Boron	9300.	5000.	2.
Chromium	50.	50.	10.
Copper	1000.	10.	10.
Manganese	50.	20.	2.5
Molybdenum	1.5×10^4	1400.	5.
Selenium	10.	5.	0.005
Vanadium	500.	30.	0.5

These MATEs should be multiplied by dilution factors before being applied to the waste streams, hence the proposed MATEs are to be judged analogous to ecological-based MATEs. Since the dilution factors may be as low as one, these proposed MATEs may also be considered health-based MATEs.

5.4.3.1 Level 2 Analysis - Solids

Figures 65 and 66 are examples of the first Level 2 analysis form properly filled out for SRC-II solid residue (stream 301, Figure 65) and gasifier slag (stream 307, Figure 66) using "average U.S. coal" for the conceptualized SRC facility. These two waste streams were chosen since the SAM/IA indicates that these waste streams will be the most hazardous. Comparison of these two figures indicates that the SRC-solid residue will be the most hazardous. However, the unreacted carbon in the SRC residue may be utilized by a hitherto undeveloped technology. The gasifier slag has no known or projected use.

1. SOURCE/CONTROL OPTION Page 1 / 7

Conceptualized SRC Facility using "Average U.S. Coal"

2. EFFLUENT STREAM

301 SRC Mineral Residue

CODE # NAME

3. EFFLUENT STREAM FLOW RATE

Q = 47000 g/sec

(gas = m³/sec — liquid = l/sec — solid = g/sec)

4. COMPLETE THE FOLLOWING TABLE FOR THE EFFLUENT STREAM OF LINE 2 (USE BACK OF FORM FOR SCRATCH WORK)

A		B	C	D	E	F	G	H	I	J
									TOXIC UNIT DISCHARGE RATE	
POLLUTANT SPECIES	CATEGORY	POLLUTANT CONCENTRATION	HEALTH MATE CONCENTRATION	ECOLOGICAL MATE CONCENTRATION	DEGREE OF HAZARD (HEALTH) (B/C)	DEGREE OF HAZARD (ECOLOGICAL) (B/D)	√ IF HEALTH MATE EXCEEDED	√ IF ECOL MATE EXCEEDED	(HEALTH BASED) (E x LINE 3)	(ECOLOGICAL BASED) (F x LINE 3)
UNITS	-	μg/g	μg/g	μg/g	—	—	—	—	g/sec	g/sec
Aluminum	38	58,960.	$1.6x10^{4}$	200	3.7	295.			$1.7x10^{5}$	$1.4x10^{7}$
Antimony	50	13.	1500.	40.	0.0087	0.32			407.	$1.5x10^{4}$
Arsenic	49	56.	50.	10.	1.1	5.6			$5.3x10^{4}$	$2.6x10^{5}$
Barium	36	1235.	1000.	500.	1.2	2.5			$5.8x10^{4}$	$1.2x10^{5}$
Beryllium	32B	7.	6.	11.	1.2	0.64			$5.5x10^{4}$	$3.0x10^{4}$
Boron	37	250.	9300.	5000.	0.027	0.050			1200.	2400.
Bromine	--	22.	--							
Cadmium	82	6.2	10.	0.20	0.62	31.			$2.9x10^{4}$	$1.5x10^{6}$
Calcium	34	105,000	$4.8x10^{4}$	3200.	2.2	33.			$1.0x10^{5}$	$1.5x10^{6}$
Cerium	84	100.	$1.1x10^{5}$		$9.1x10^{4}$				43.	

IF MORE SPACE IS NEEDED, USE A CONTINUATION SHEET

5. EFFLUENT STREAM DEGREE OF HAZARD

HEALTH MATE BASED (Σ COL. E) 5a 340

ECOLOGICAL MATE BASED (Σ COL. F) 5b 2400

(ENTER HERE AND AT LINE 8, FORM IA01)

6. NUMBER OF POLLUTANTS COMPARED TO MATES

HEALTH 6a 74

ECOLOGICAL 6b 43

7. TOXIC UNIT DISCHARGE SUM

HEALTH MATE BASED (Σ COL. I) 7a $1.6x10^{7}$ g/sec

ECOLOGICAL MATE BASED (Σ COL. J) 7b $1.1x10^{8}$ g/sec

(ENTER HERE AND AT LINE 8, FORM IA01)

Figure 65. Level 2 analysis for SRC mineral residue

SOURCE/CONTROL OPTION Conceptualized SRC Facility EFFLUENT STREAM NO. 301

A		B	C	D	E	F	G	H	I	J
									TOXIC UNIT DISCHARGE RATE	
POLLUTANT SPECIES	CATEGORY	POLLUTANT CONCENTRATION	HEALTH MATE CONCENTRATION	ECOLOGICAL MATE CONCENTRATION	DEGREE OF HAZARD (HEALTH) (B/C)	DEGREE OF HAZARD (ECOLOGICAL) (B/D)	√ IF HEALTH MATE EXCEEDED	√ IF ECOL MATE EXCEEDED	(HEALTH BASED) (E x LINE 3)	(ECOLOGICAL BASED) (F x LINE 3)
UNITS	—	μg/g	μg/g	μg/g	—	—	—	—	g/sec	g/sec
Cesium	31	6.7	2.5x10^{5}		2.7x10^{-5}				1.3	
Chlorine		3600.	2.5x10^{5}		0.014				650.	
Chromium	68	120.	50.	50.	2.4	2.4			1.1x10^{5}	1.1x10^{5}
Cobalt	74	44.	150.	50.	0.29	0.88			1.4x10^{4}	4.1x10^{4}
Copper	78	83.	1000.	10.	0.083	8.3			3900.	3.9x10^{5}
Europium		1.5								
Gallium	39	20.	1.5x10^{4}		0.0013				6.3	
Hafnium	64	4.1	150.		0.027				1300.	
Iron	72	92,000	300.	50.	310.	1800.			1.4x10^{7}	8.6x10^{7}
Lanthanum	84	57.	3.4x10^{5}		1.7x10^{-4}				7.9	
Lead	46	68.	50.	10.	1.4	6.8			6.4x10^{4}	3.2x10^{5}
Magnesium	33	5000.	1.8x10^{4}	1.7x10^{4}	0.28	0.29			1.3x10^{4}	1.4x10^{4}
Manganese	71	240.	50.	20.	4.8	12			2.3x10^{5}	5.6x10^{5}
Mercury	83	0.76	2.0	50.	0.38	0.015			1.8x10^{4}	710.
Molybdenum	69	22.	1.5x10^{4}	1400.	0.0015	0.016			69.	740.
Nickel	76	95.	45.	2.0	2.1	48.			9.9x10^{4}	2.2x10^{6}
Potassium	29	18000.	6000.	4600.	3.0	3.9			1.4x10^{5}	1.8x10^{5}
Rubidium	30	240.	3.6x10^{5}		6.7x10^{-4}				31.	

Figure 65. (continued)

SOURCE/CONTROL OPTION Conceptualized SRC Facility EFFLUENT STREAM NO. 301

A		B	C	D	E	F	G	H	I	J
									TOXIC UNIT DISCHARGE RATE	
POLLUTANT SPECIES	CATEGORY	POLLUTANT CONCENTRATION	HEALTH MATE CONCENTRATION	ECOLOGICAL MATE CONCENTRATION	DEGREE OF HAZARD (HEALTH) (B/C)	DEGREE OF HAZARD (ECOLOGICAL) (B/D)	√ IF HEALTH MATE EXCEEDED	√ IF ECOL MATE EXCEEDED	(HEALTH BASED) (E x LINE 3)	(ECOLOGICAL BASED) (F x LINE 3)
UNITS	—	μg	μg	μg	—	—	—	—		
Samarium	84	7.4	$1.6\text{x}10^5$		$4.6\text{x}10^{-5}$				2.2	
Scandium	60	16.	$1.6\text{x}10^5$		$1.0\text{x}10^4$				4.7	
Selenium	54	20.	10.	5.	2.0	4.0			$9.4\text{x}10^4$	$1.9\text{x}10^5$
Sodium	47A	19,000.	$1.6\text{x}10^5$		0.12				5600.	
Strontium	35	560.	9200.		0.061				2900.	
Tantalum	67	1.0	$1.5\text{x}10^4$		$6.7\text{x}10^{-5}$				3.1	
Terbium		0.68								
Thallium	41	3.5	300.		0.012				550.	
Thorium	85	23.	130.		0.18				8300.	
Titanium	62	1500.	$1.8\text{x}10^4$	160.	0.083	9.4			3900.	$4.4\text{x}10^5$
Uranium	85	15.	$1.2\text{x}10^4$	100.	0.0012	0.15			59.	7050.
Vanadium	65	150.	500.	30.	0.30	5.0			$1.4\text{x}10^4$	$2.4\text{x}10^5$
Zinc	81	400.	5000.	20.	0.080	20.			3800.	$9.4\text{x}10^5$
Zirconium	63	320.	1500.		0.21				$1.0\text{x}10^4$	
Indane	15	85.	$6.8\text{x}10^5$		$1.2\text{x}10^4$				5.9	
Methylindane	15	40.	$6.8\text{x}10^5$		$5.9\text{x}10^5$				2.8	
Dimethylindane	15	25.	$6.8\text{x}10^5$		$3.7\text{x}10^5$				1.7	
Tetralin	15	110.	$4.0\text{x}10^5$	200.	$2.8\text{x}10^4$	0.55			13.	$2.6\text{x}10^4$

Figure 65. (continued)

SOURCE/CONTROL OPTION Conceptualized SRC Facility EFFLUENT STREAM NO. 301

A		B	C	D	E	F	G	H	I	J
									TOXIC UNIT DISCHARGE RATE	
POLLUTANT SPECIES	CATEGORY	POLLUTANT CONCENTRATION	HEALTH MATE CONCENTRATION	ECOLOGICAL MATE CONCENTRATION	DEGREE OF HAZARD (HEALTH) (B/C)	DEGREE OF HAZARD (ECOLOGICAL) (B/D)	√ IF HEALTH MATE EXCEEDED	√ IF ECOL MATE EXCEEDED	(HEALTH BASED) (E x LINE 3)	(ECOLOGICAL BASED) (F x LINE 3)
UNITS	—	μg	μg	μg	—	—	—	—		
6-Methyl-tetralin	15	50.	4.0×10^5	200.	1.2×10^4	0.25			5.9	1.2×10^4
Naphthalene	21	1500.	1.5×10^5	20.	0.01	75.			470.	3.5×10^6
2-Methyl-napthalene	21	740.	6.8×10^5		0.0011				51.	
1-Methyl-napthalene	21	180.	6.8×10^5		2.6×10^4				12.	
Dimethyl-napthalene	21	470.	6.8×10^5		6.9×10^4				32.	
2-Isorpoly-napthalene	21	2.	6.8×10^5		2.9×10^6				0.14	
1-Isorpoly-napthalene	21	1.	6.8×10^5		1.5×10^6				0.069	
C4-napthalene	21	15.	6.8×10^5		2.2×10^5				1.0	
Cyclohexyl-benzene	15	1								
Biphenyl	15	5	3000.		0.0017				78.	
Acenapthylene	21	270.								
Dimethylbiphenyl	15	61.			0.020				960.	
Dibenzofuran		60								
Xanthene		20.								
Dibenzothiophene		70.								
Methyldi-benzothiophene		8.								
Dimethyldi-benzothiophene		20.								
Thioxanthene		5								

Figure 65. (continued)

SOURCE/CONTROL OPTION ______ EFFLUENT STREAM NO. ______

A		B	C	D	E	F	G	H	I	J
									TOXIC UNIT DISCHARGE RATE	
POLLUTANT SPECIES	CATEGORY	POLLUTANT CONCENTRATION	HEALTH MATE CONCENTRATION	ECOLOGICAL MATE CONCENTRATION	DEGREE OF HAZARD (HEALTH) (B/C)	DEGREE OF HAZARD (ECOLOGICAL) (B/D)	√ IF HEALTH MATE EXCEEDED	√ IF ECOL MATE EXCEEDED	(HEALTH BASED) (E x LINE 3)	(ECOLOGICAL BASED) (F x LINE 3)
UNITS	—	μg/g	μg/g	μg/g	—	—	—	—	g/sec	g/sec
Fluorene		80.								
9-Methylfluorene		40.								
1-Methylfluorene		50.								
Antracene/ Phenanthrene	21	500.	1.7×10^{5}		0.10				4900.	
Methyl-phenanthrene	21	100.	9.1×10^{4}		0.0011				52.	
1-Methyl-phenanthrene	21	50.	9.1×10^{4}		5.5×10^{4}				26.	
C_2-Antrhacene	21	10.								
Fluoranthene	22	200.	2.8×10^{5}		7.1×10^{-4}				34.	
Dihydropyrene		10.								
Pyrene	21	200.	6.9×10^{5}		2.9×10^{-4}				14.	
n-undecane	1A	90.	1.1×10^{6}	2.0×10^{4}	8.2×10^{-5}	0.0045			3.8	210.
n-dodecane	1A	550.	1.1×10^{6}	2.0×10^{4}	5.0×10^{-4}	0.028			24.	1300.
n-tridecane	1A	9100.	1.1×10^{6}	2.0×10^{4}	0.0083	0.46			390.	2.1×10^{4}
n-tetradecane	1A	210	1.1×10^{6}	2.0×10^{4}	1.9×10^{-4}	0.010			9.0	490.
n-pentadecane	1A	80.	1.1×10^{6}	2.0×10^{4}	7.3×10^{-5}	0.0040			3.4	190.
n-hexadecane	1A	50.	1.1×10^{6}	2.0×10^{4}	4.5×10^{-5}	0.0025			2.1	120.
n-heptadecane	1A	20.	1.1×10^{6}	2.0×10^{4}	1.8×10^{-5}	0.0010			0.85	47.
n-octadecane	1A	10.	1.1×10^{6}	2.0×10^{4}	9.1×10^{-6}	5.0×10^{-4}			0.43	24.

Figure 65. (continued)

SOURCE/CONTROL OPTION Conceptualized SRC Facility EFFLUENT STREAM NO. ______

A		B	C	D	E	F	G	H	I	J
									TOXIC UNIT DISCHARGE RATE	
POLLUTANT SPECIES	CATEGORY	POLLUTANT CONCENTRATION	HEALTH MATE CONCENTRATION	ECOLOGICAL MATE CONCENTRATION	DEGREE OF HAZARD (HEALTH) (B/C)	DEGREE OF HAZARD (ECOLOGICAL) (B/D)	√ IF HEALTH MATE EXCEEDED	√ IF ECOL MATE EXCEEDED	(HEALTH BASED) (E x LINE 3)	(ECOLOGICAL BASED) (F x LINE 3)
UNITS	—	μ g	μ g	μ g	—	—	—	—		
n-nonadecane	1A	14.	$1.1x10^6$	$2.0x10^4$	$1.3x10^5$	$7.0x10^4$			0.60	33.
n-eicosane	1A	14.	$1.1x10^6$	$2.0x10^4$	$1.3x10^5$	$7.0x10^4$			0.60	33.
n-heneicosane	1A	16.	$1.1x10^6$	$2.0x10^4$	$1.3x10^5$	$8.0x10^4$			0.68	38.
n-docosane	1A	14.	$1.1x10^6$	$2.0x10^4$	$1.3x10^5$	$7.0x10^4$			0.60	33.
n-tricosane	1A	14.	$1.1x10^6$	$2.0x10^4$	$1.3x10^5$	$7.0x10^4$			0.60	33.
n-tetracosane	1A	10.	$1.1x10^6$	$2.0x10^4$	$9.1x10^6$	$5.0x10^4$			0.43	24.
others	1A	26.	$1.1x10^6$	$2.0x10^4$	$2.4x10^5$	0.0013			1.1	61.

Figure 65. (continued)

NOTES

Estimated MATEs for alkanes of C_9 or larger:

health ca. 1.1×10^6, ecological ca. 2.0×10^4

MATEs for substituted indanes, tetralins, biphenyl assumed equal to unsubstituted compound.

Ecological potassium MATE estimated to be 4600.

Assume all antrhacene/phenanthrene present as phenanthrene (worst case) to calculates the Potential Degree of Hazard and Potential Toxic Unit Discharge Rate.

ASSUMPTIONS

LIST ALL ASSUMPTIONS MADE REGARDING FLOW RATE, EMISSION FACTORS AND MATE VALUES.

Figure 65. (continued)

Page 1 /

1. SOURCE/CONTROL OPTION

Conceptualized SRC Facility Using "Average U.S. Coal"

2. EFFLUENT STREAM

307 CODE # — Gasifier Slag NAME

3. EFFLUENT STREAM FLOW RATE

Q = 11000 g/sec.

(gas = m³/sec — liquid = l/sec — solid = g/sec)

4. COMPLETE THE FOLLOWING TABLE FOR THE EFFLUENT STREAM OF LINE 2 (USE BACK OF FORM FOR SCRATCH WORK)

A		B	C	D	E	F	G	H	I	J
									TOXIC UNIT DISCHARGE RATE	
POLLUTANT SPECIES	CATEGORY	POLLUTANT CONCENTRATION	HEALTH MATE CONCENTRATION	ECOLOGICAL MATE CONCENTRATION	DEGREE OF HAZARD (HEALTH) (B/C)	DEGREE OF HAZARD (ECOLOGICAL) (B/D)	√ IF HEALTH MATE EXCEEDED	√ IF ECOL MATE EXCEEDED	(HEALTH BASED) (E x LINE 3)	(ECOLOGICAL BASED) (F x LINE 3)
UNITS	–	μg/g	μg/g	μg/g	—	—	—	—	g/sec	g/sec
Antimony	50	13.	1500.	40.	0.0087	0.32			95.	3600.
Arsenic	49	24.	50.	10.	0.48	2.4			5300.	$2.6x10^4$
Barium	36	420.	1235.	1000.	0.34	0.42			3700.	4600.
Bromine		27.								
Calcium	34	13090.	$4.8x10^4$	3200.	0.27	4.1			3000.	$4.5x10^4$
Cerium	84	170.	$1.1x10^5$		0.0015				17.	
Cesium	31	10.	$2.5x10^5$		$4.0x10^5$				0.44	
Chromium	68	34.	50	50	0.68	0.68			7500.	7500.
Cobalt	74	57.	150	50	0.38	1.1			4200.	$1.3x10^4$
Copper	78	32.	1000	10	0.032	3.2			350.	$3.5x10^4$

IF MORE SPACE IS NEEDED, USE A CONTINUATION SHEET

5. EFFLUENT STREAM DEGREE OF HAZARD

HEALTH MATE BASED (Σ COL. E) 5a 160

ECOLOGICAL MATE BASED (Σ COL. F) 5b 800.

(ENTER HERE AND AT LINE 8, FORM IA01)

6. NUMBER OF POLLUTANTS COMPARED TO MATES

HEALTH 6a 29.

ECOLOGICAL 6b 16.

7. TOXIC UNIT DISCHARGE SUM

HEALTH MATE BASED (Σ COL. I) 7a $1.8x10^6$ g/sec

ECOLOGICAL MATE BASED (Σ COL. J) 7b $8.8x10^6$ g/sec

(ENTER HERE AND AT LINE 8, FORM IA01)

Figure 66. Level 2 analysis for gasifier slag

SOURCE/CONTROL OPTION SRC Facility EFFLUENT STREAM NO.

A		B	C	D	E	F	G	H	I	J
									TOXIC UNIT DISCHARGE RATE	
POLLUTANT SPECIES	CATEGORY	POLLUTANT CONCENTRATION	HEALTH MATE CONCENTRATION	ECOLOGICAL MATE CONCENTRATION	DEGREE OF HAZARD (HEALTH) (B/C)	DEGREE OF HAZARD (ECOLOGICAL) (B/D)	√ IF HEALTH MATE EXCEEDED	√ IF ECOL MATE EXCEEDED	(HEALTH BASED) (E x LINE 3)	(ECOLOGICAL BASED) (F x LINE 3)
UNITS	—	μ	μ	μ	—	—	—	—		
Europium		3.3								
Hafnium	64	4.2	150.		0.028				310.	
Iron	72	37,000.	300.	50.	120.	740.			$1.4\text{x}10^6$	$8.1\text{x}10^6$
Lanthanum	84	84.	$3.4\text{x}10^5$		$2.5\text{x}10^4$				2.7	
Lead	46	20.	50.	10.	0.40	2.0			4400.	$2.2\text{x}10^4$
Lutetium		0.93								
Manganese	71	97.	50.	20.	1.9	4.8			$2.1\text{x}10^4$	$5.3\text{x}10^4$
Mercury	83	0.0093	2.0	50.	0.0045	$1.9\text{x}10^4$			51.	2.0
Neodymium	84	81.								
Nickel	76	42.	45.	2.0	0.93	21.			$1.0\text{x}10^4$	$2.3\text{x}10^5$
Potassium	29	4100.	6000.	4600.	0.68	0.89			7500.	9800.
Rubidium	30	56.	$3.6\text{x}10^5$		$1.6\text{x}10^4$				1.7	
Samarium	84	16.	$1.6\text{x}10^5$		$1.0\text{x}10^4$				1.1	
Scandium	60	28.	$1.6\text{x}10^5$		$1.6\text{x}10^4$				1.8	
Selenium	54	7.2	10.	5.	0.72	1.4			7900.	$1.6\text{x}10^4$
Silicon	43	39000.	$3.0\text{x}10^4$		1.3				$1.4\text{x}10^4$	
Sodium	47A	$5.1\text{x}10^6$	$1.6\text{x}10^5$		32.				$3.5\text{x}10^5$	
Strontium	35	230.	9200.		0.025				280.	

Figure 66. (continued)

SOURCE/CONTROL OPTION ____________ EFFLUENT STREAM NO. ____________

A		B	C	D	E	F	G	H	I	J
									TOXIC UNIT DISCHARGE RATE	
POLLUTANT SPECIES	CATEGORY	POLLUTANT CONCENTRATION	HEALTH MATE CONCENTRATION	ECOLOGICAL MATE CONCENTRATION	DEGREE OF HAZARD (HEALTH) (B/C)	DEGREE OF HAZARD (ECOLOGICAL) (B/D)	√ IF HEALTH MATE EXCEEDED	√ IF ECOL MATE EXCEEDED	(HEALTH BASED) (E x LINE 3)	(ECOLOGICAL BASED) (F x LINE 3)
UNITS	—	μg	μg	μg	—	—	—	—		
Sulfur	53	18000.								
Tantalum	67	1.1	$1.5x10^4$		$7.3x10^5$				0.81	
Terbium		2.0								
Thorium	85	18.	130.		0.14				1500.	
Titanium	62	950.	$1.8x10^4$	160.	0.053	5.9			580.	$6.5x10^4$
Ytterbium		6.3								
Zinc	81	180.	5000.	20.	0.036	9.0			400.	$9.9x10^4$

Figure 66. (continued)

5.5 Product Impacts

This section examines the potential impacts from SRC products and will cover: toxicity of products, spills and water contamination, fire hazard, and utilization (combustion) of SRC product. Regulations which would serve to limit or alleviate hazardous impacts in those areas are summarized.

5.5.1 Summary of Toxic Substances Standards

There are no environmental regulations that pertain directly to regulating the level of toxic substances in SRC product. Regulatory controls would generally be implemented only when the product is discharged, spilled or burned. SRC product does, however, contain toxic compounds and could potentially be regulated by toxic substances standards, promulgated in response to the Toxic Substances Control Act (TSCA) of 1976. The regulatory approach of TSCA provides for direct control of new and existing chemicals, requires pre-market screening of new chemicals, and provides for authority to require the testing of a chemical to determine the extent of toxicity. A major significance of TSCA is that is provides authority to develop information on the impact of chemical substances on the water environment, and allows for broad control of chemicals. If adequate controls cannot be developed through the FWPCA or the Safe Drinking Water Act, action could be invoked under the Toxic Substance Control Act. To date, no toxic substances standards have been promulgated which would impact SRC operations.

Product spills may be subject to regulation under the National Pollutant Discharge Elimination System (NPDES) of the Clean Water Act, as discussed in Section 5.3.1. A proposed rule (40 CFR part 151) would establish requirements for spill prevention control and countermeasure (SPCC) plans to prevent discharges of hazardous substances from facilities subject to permitting requirements of the NPDES. Facilities which become operational after the effective rule date shall prepare an SPCC plan before such facility begins operations and shall be fully implemented as soon as possible, but no later than six months after the facility begins operations.

The SPCC plan shall be prepared in accordance with good engineering practices and the general requirements of providing for appropriate contaminant, drainage control and/or diversionary structures. Specific requirements include the following:

- In liquid storage areas, and truck/rail car liquid loading and unloading areas secondary contaminent should be sufficient to contain the capacity of the largest single container or tank in the drainage system, plus allowance for precipitation accumulation. Secondary containment systems shall be sufficiently impervious to contain spilled hazardous material until it can be removed or treated.

- Raw materials storage areas which are subject to runoff, leaching, or dispersal by wind shall incorporate drainage or other control features which will prevent the discharge of hazardous substances.

- All areas of the facility shall be inspected at specified intervals for leaks or conditions that could lead to discharges.

- Only uncontaminated rainwater may be released from diked or other plant drainage areas unless the released water will be given approved treatment.
- Facilities shall have the necessary security systems to prevent accidental or international entry which could cause a discharge.
- Facility employees and contractor personnel using the facility shall be trained in and informed of preventive measures at the facility.

Standards applying to pollutant release into the various media (air, water and land) have been discussed previously in Sections 5.2.1, 5.3.1 and 5.4.1, respectively.

5.5.2 Comparison of Product Characterization Data with Toxic Substances Standards

Given the absence of numerical toxic substances standards, a comparison between such standards and the product compositions cannot be made.

5.5.3 Environmental Impacts

5.5.3.1 Multimedia Impacts of Accidental Spills

A spill of SRC products containing toxic and hazardous compounds would be an environmental concern. Knowledge of ways in which impact from spills differ from those of continuous discharge of a substance and the precautions which can be taken to combat spill impact are important.

The problem of potential spills is distinctly different from that of continuous discharges. Spill pollution differs from background pollution in several important ways:

- There is no specific advance knowledge with regard to when or where a spill may occur, the amount of material involved, the resulting concentration, the size of the affected environment, and the duration of the episode.
- Spills generally involve much higher environmental concentrations than found in background pollution. However, these high concentrations may not last as long and may be in a more limited area.
- Preventive measures can do much to reduce frequency and size of spills but spills cannot be totally eliminated.
- Perhaps the most important difference between spill and background pollution situations lies in the need for immediate action to evaluate the hazard of a spill and to institute control measures.

The basic data required to evaluate the effects of SRC product oil on man and his environment under the spill situation are generally the same as are required for the evaluation of continuous discharges. These descriptors of the spill include time, place, quantity, physical and chemical properties, ecosystems at risk, and toxicity. Much of these data can be acquired in advance of a spill and stored for ready access at the time of the emergency.

Following a spill, it is necessary not only to predict the distribution of the material but also to monitor its dispersal into the environment until such time as dilution, degradation, or other mechanisms have reduced the contamination to a safe level.

Primary information needed to protect the population from the immediate effects of the spilled material includes acute and subacute toxicity data for exposure through inhalation, skin contact or ingestion of the material, or the contamination of food and drinking water. Information on sublethal, disabling concentrations are particularly important for the protection of those involved in controlling and cleaning up spilled chemicals.

Spill situations should be exploited to gain the greatest possible knowledge of effects from exposure to SRC product. Primary emphasis should be placed on effects on human health. Field studies should be undertaken to determine effects on the biota and the ability of damaged ecosystems to recover. Studies of model ecosystems, subjected to spill size quantities of product oil would, of course, be most helpful for predicting spill hazard.

Special attention should be given to development of analytical and biological measurement techniques for use in spill situations. Relatively simple mathematical models should be developed for predicting the movement and concentrations of hazardous materials in those ecosystems likely to be subjected to spills. These models, together with information on the effects of exposure, can be utilized to determine whether a hazard exists.

Approximately 11,368 Mg/day of product and by-product will be produced in the commercial SRC process. These products and by-products must be stored and shipped to buyers. A breakdown in production rates for SRC-II is as follows:

Product or By-Product (1)	Mg/day (1)
Naphtha	518.2
Fuel oil	2,591.
SRC	5,527.
Ammonia	63.9
Sulfur	442.3
Phenol	34.4
SNG	1,312.
LPG	820.7

The hazardous nature of these materials requires that every precaution be taken to avoid spills and leaks during storage and shipping. Both preventive measures and recovery/disposal methods are required to negate the potential environmental disaster of spills. The toxic nature of SRC products can be appreciated from the analysis of SRC-I products shown in Section 3.0. Available MATE values for organic constituents in SRC-I products are presented in Table 106. A complete analysis of products from SRC-II is not available.

The several preventative measures that will act to mitigate syncrude spills are as follows:

- Structural integrity must conform to code construction and the materials must be stored in compatible materials.

- Methods to prevent and repair corrosion are needed.

TABLE 106. CONCENTRATIONS (mg/1) OF CONSTITUENTS IDENTIFIED IN SRC PRODUCTS

PNA Fraction	Light Oil	Wash Solvent	Process Solvent	Raw Process Water	Mineral Residue	Solvent Refined Coal	Particulate Filter Concentration ug/m^3	MATE-Water (mg/1) Based on Health Effects	MATE-Water (mg/1) Based on Ecological Effects
Xylene		1300						6500	1
o-ethylbenzene	9800	1700						6500	1
m/p-ethylbenzene		700						6500	1
C_3-benzene	3900	1500						45	1
C_4-benzene		500						45	1
Indane	4300	13000						3400	2
Tetralin	330	4100		0.1	110			2000	1
Napthalene	1630	32000	100	5	1500			750	0.1
Biphenyl	80	10000	5900	0.2	270	2	75	15	
Pyrene	20	40	11200	0.6	200	280	900	3450	
Fluoranthene	15	35	10500	0.4	200	180	700	1400	

- Periodic examination of tank integrity is required.
- Mobile storage tanks should be isolated from navigable waters.
- Heating coils, where used, must be monitored for oil content; external heating systems rather than internal structural coils should be used.
- Tanks must be gauged carefully before filling to prevent overfill.
- Overflow pipes should be connected to adjacent tanks.
- Relief valves for excessive pressure and vacuum should be in place.
- Inspection methods should concentrate on target areas, including pipeline exposure, pipeline crossing and areas of construction.
- Oil sensitive probes should be located throughout the drainage system of a potential spill.

If an oil spill does occur within the confines of the plant it can be expected to be contained. Dikes are required to contain the maximum spill and must be covered with an impervious material around each storage tank. In draining these dikes, contaminated waters will be routed to the chemical water sewer.

5.5.3.2 Fire and Explosion Hazard

The SRC products pose some degree of hazard with regard to fire and explosion hazard. Figure 67 illustrates the possible fire reaction chains that could result from leaks in manufacturing equipment or accidental product spillage. The fire/explosion hazard of SRC products would be expected to be similar to that of comparable petroleum products and should require similar precautions.

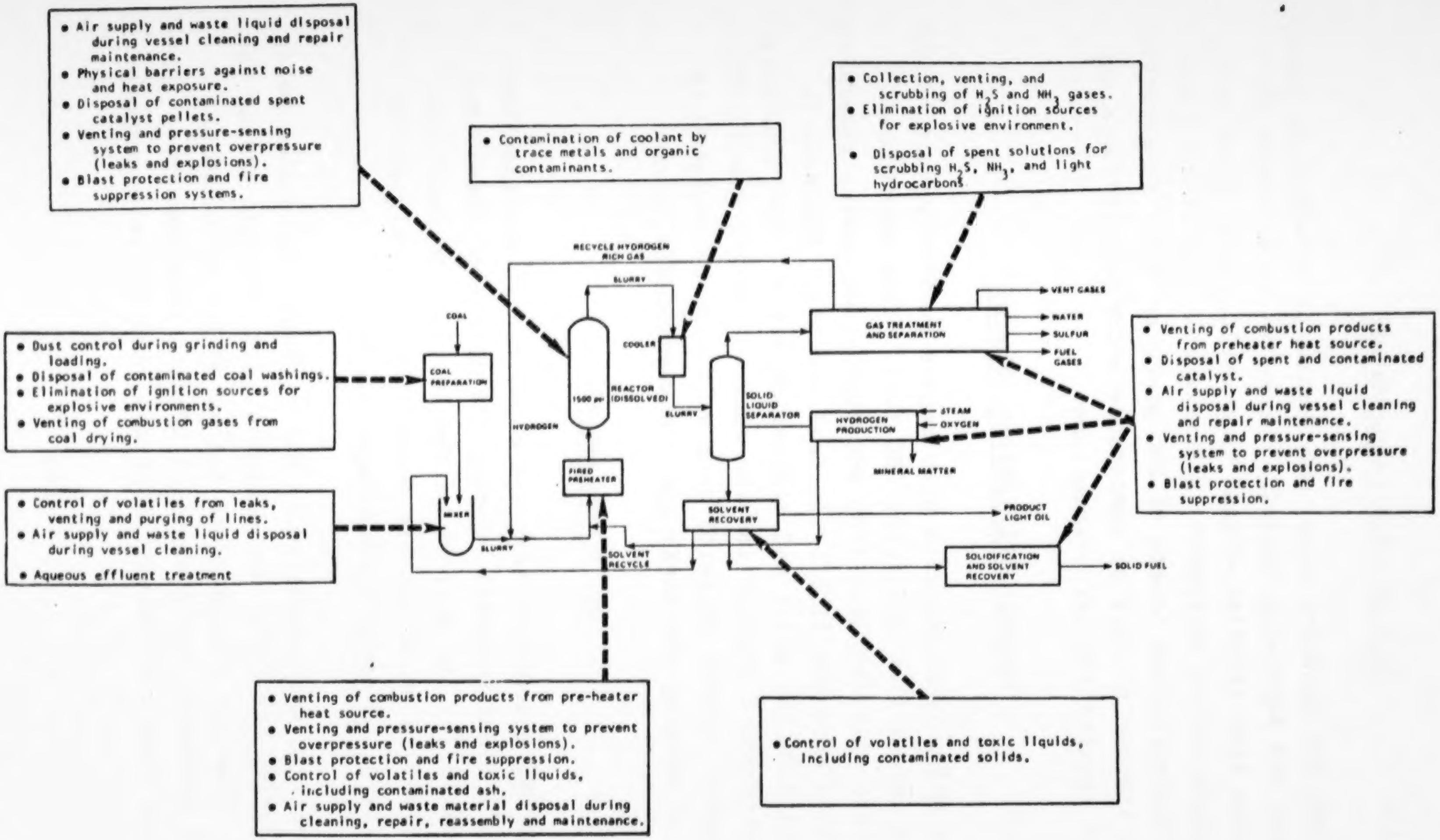
5.5.3.3 Product Utilization Impacts

A major consideration with regard to SRC product hazard is the impact from utilizing SRC fuel. This section will summarize emission data from SRC combustion tests, comparing emissions from SRC-I, SRC-II, coal and oil. The data is derived from two major SRC combustion tests - one utilizing the solid SRC-I product and the other utilizing liquid SRC-II product. These emission data will also be reviewed in terms of meeting standards and recommended MEG values.

5.5.3.3.1 SRC-I Combustion

An SRC combustion test was conducted at Georgia Power Company's Plant Mitchell, during the months of March, May, and June 1977. The purpose of the test was to determine whether SRC is an acceptable substitute for coal, and to demonstrate the assumed advantages of SRC.

The test was conducted in three phases, with coal being fired during the first and second phases, and SRC during the third. Flue gas samples were collected for modified EPA Level I analysis, and analytical results were reported. Air emissions from the combustion of coal and SRC were compared


COAL
COAL PREPARATION
MIXER
SLURRY
HYDROGEN
RECYCLE HYDROGEN RICH GAS
SLURRY
1500 psi
REACTOR (DISSOLVED)
FIRED PREHEATER
COOLER
SLURRY
SOLID LIQUID SEPARATOR
SOLVENT RECYCLE
SOLVENT RECOVERY
GAS TREATMENT AND SEPARATION
VENT GASES
WATER
SULFUR
FUEL GASES
HYDROGEN PRODUCTION
STEAM
OXYGEN
MINERAL MATTER
PRODUCT LIGHT OIL
SOLIDIFICATION AND SOLVENT RECOVERY
SOLID FUEL

- Air supply and waste liquid disposal during vessel cleaning and repair maintenance.
- Physical barriers against noise and heat exposure.
- Disposal of contaminated spent catalyst pellets.
- Venting and pressure-sensing system to prevent overpressure (leaks and explosions).
- Blast protection and fire suppression systems.

- Contamination of coolant by trace metals and organic contaminants.

- Collection, venting, and scrubbing of H_2S and NH_3 gases.
- Elimination of ignition sources for explosive environment.
- Disposal of spent solutions for scrubbing H_2S, NH_3, and light hydrocarbons.

- Dust control during grinding and loading.
- Disposal of contaminated coal washings.
- Elimination of ignition sources for explosive environments.
- Venting of combustion gases from coal drying.

- Venting of combustion products from preheater heat source.
- Disposal of spent and contaminated catalyst.
- Air supply and waste liquid disposal during vessel cleaning and repair maintenance.
- Venting and pressure-sensing system to prevent overpressure (leaks and explosions).
- Blast protection and fire suppression.

- Control of volatiles from leaks, venting and purging of lines.
- Air supply and waste liquid disposal during vessel cleaning.
- Aqueous effluent treatment

- Venting of combustion products from pre-heater heat source.
- Venting and pressure-sensing system to prevent overpressure (leaks and explosions).
- Blast protection and fire suppression.
- Control of volatiles and toxic liquids, including contaminated ash.
- Air supply and waste material disposal during cleaning, repair, reassembly and maintenance.

- Control of volatiles and toxic liquids, including contaminated solids.

Figure 67. Coal liquefaction environmental health and safety impact and hazard control requirements (132)

for various organic and inorganic constituents, and SO_2 and NO_x. Finally, the impact of the air emissions from the combustion of SRC was assessed by comparison with EPA's Multimedia Environmental Goals and existing New Source Performance Standards.

Air quality emissions test data shown in Table 107 indicates that SRC SO_2 and NO_x emissions were 0.46 and 0.19 kg/GJ (1.06 and 0.43 lb/10^6 Btu) respectively. This is about 12 and 39 percent under the existing New Source Performance Standards (NSPS) of 0.52 kg/GJ (1.2 lbs/10^6 Btu) for SO_x and 0.30 kg/GJ (0.7 lbs/10^6 Btu) for NO_x. If the SO_2 standard is reduced to 0.26 kg/GJ (0.6 lbs/10^6 Btu), SRC derived from high sulfur coal may not achieve compliance. SO_x levels were slightly higher than that of the low sulfur coal normally burned at the plant. The sulfur content of the SRC prior to combustion was approximately 0.9 percent as compared to an estimated 0.6 percent sulfur in the Kentucky coal. The NO_x emissions were unexpectedly low and may be a result of abnormally high excess air used during the combustion test; thus additional testing at normal conditions is required.

Particulate emissions were at levels which can be controlled well below the EPA standard of 0.04 kg/GJ (0.1 lbs/10^6 Btu) by installing a modern precipitator having a particulate collection efficiency of approximately 95 percent.

During coal combustion highly volatile trace elements may appear in the combustion gases. The concentration of most of the trace elements in combustion gases from SRC derived from high sulfur coal are lower than those resulting from direct combustion of low sulfur coal. This comparison is made in Table 108, although the coal used to produce the

TABLE 107. COMPARISON OF COMBUSTION EMISSIONS TO STANDARDS FOR SOLID FOSSIL FUEL-FIRED STEAM GENERATORS

	Solid Fossil Fuel		
Contaminant	Existing Standards	Proposed Standards	SRC-I Ave. Emission Rate
SO_x	1.2 lb/10^6 Btu (520 ng/J)	0.6 lb/10^6 Btu 260 ng/J	1.06 lb/10^6 Btu (460 ng/J)
NO_x	0.7 lb/10^6 Btu (300 ng/J)	0.43 lb/10^6 Btu (190 ng/J)	
Particulates	0.1 lb/10^6 Btu (43 ng/J)		

TABLE 108. COMPARISON OF INORGANIC AIR EMISSIONS -- COAL VS. SRC

Constituent	Coal May 25, 1977 $\mu g/m^3$	SRC ** June 14, 1977 $\mu g/m^3$
Aluminum	809.98	215.03
Antimony	4.55	3.57
Arsenic	2.32	1.42
Barium	48.23	11.71
Boron	0.24	1.95
Chromium	57.13	16.61
Copper	8.30	0.63
Lead	6.24	1.40
Iron	1,268.94	799.62
Magnesium	138.15	57.60
Manganese	29.81	62.55
Mercury	0.57	2.06
Nickel	82.33	13.46
Thorium	7.96	1.08
Uranium	0.20	3.53
Vanadium	12.28	5.91
Zinc	12.88	9.02

*It should be noted that the coal used to produce the SRC was not the coal fired on May 25, 1977. It is known, however, that solvent refining of coal results in the removal of some highly volatile trace elements, such that, when SRC is burned, lower concentrations of these elements generally should appear in the combustion gas.

SRC was not the coal fired on May 25, 1977. It is known however, that solvent refining of coal results in the removal of some highly volatile trace elements, such that, when SRC is burned, lower concentrations of these elements generally should appear in the combustion gases.

The concentration of inorganic elements in air emissions from the SRC-I combustion test are compared in Table 109 to the MEG for those elements. All elements meet the recommended MATE values, with the exception of chromium. Zinc and boron are the only elements which meet the ambient level goal values. None of the elements meet the elimination of discharge. It should be remembered, however, that these trace element emission levels are generally less for SRC than for coal.

Air emission analysis was not performed, however. There are three elements (titanium, beryllium, and cobalt) which are reported at levels in SRC product oil that could potentially pose a pollution problem when burned. The inclusion of these elements in future air emission studies could resolve this uncertainty.

The release of organic constituents to the air via combustion of SRC is not an area of major environmental concern. C_1-C_6 hydrocarbons were not detected during either Phase II or Phase III. The detection limit for these compounds was 0.5 ppm. The emissions of C_7 through C_{12} hydrocarbons during the combustion of SRC do not appear to differ significantly from the direct combustion of coal and are not an area of environmental concern. Also, no carcinogenic PAHs were found in the SRC flue gases.

TABLE 109. COMPARISON OF SRC AIR EMISSIONS WITH MEG's

Constituent	Minimum Acute Toxicity Effluent		SRC-I
	Based on Health Effects*	Based on Ecological Effects*	June 14, 1977*
Aluminum	5,200	---	215.03
Antimony	500	---	3.57
Arsenic	2	---	1.42
Barium	500	---	11.71
Boron	3,100	---	1.95
Chromium	1	---	16.61
Copper	200	---	0.63
Iron	---	---	799.62
Lead	150	---	1.40
Magnesium	6,000	---	57.90
Manganese	5,000	---	62.55
Mercury	50	10	2.06
Nickel	15	---	13.46
Thorium	---	---	1.08
Uranium	9	---	3.53
Vanadium	500	1	5.91
Zinc	4,000	---	9.02

* Values are in $\mu g/m^3$

--- Values have not yet been developed

There could be a problem with fugitive dust from handling SRC, the extent of which will be determined by the equipment use.

5.5.3.3.2 SRC-II Combustion

A combustion test was performed by Consolidated Edison of New York on the liquid product from SRC-II. The test was performed at Con Ed's 74th Street generating station on a tangentially fired boiler manufactured by Combustion Engineering (characteristically a low NO_x producer). Some 5,000 barrels of SRC-II from the Fort Lewis pilot plant were burned. A petroleum fuel, burned as the control was a little lighter than No. 6 residual oil. The SRC-II liquid contained one percent nitrogen by weight, compared to 0.23 percent in the oil. Sulfur levels were more comparable: 0.22 percent in SRC-II; 0.24 percent in the oil.

A summary of the preliminary results of the study are shown in Table 110, along with existing and proposed standards. NO_x emissions from SRC-II were 70 percent higher than for conventional petroleum. The Electric Power Research Institute believes, however, that a utility boiler capable of meeting the existing NO_x standard for oil ($0.13\ g/10^6\ J$) would, burning SRC-II, be able to meet the level of discharge currently being considered for proposed as a standard for coal-derived liquids ($0.22\ g/10^6\ J$). It should be noted that no standards have been officially proposed at the time of this writing and that the value states above is subject to revision. The U.S. EPA is mandated to establish New Source Performance Standards for all new major stationery sources by 1982. Although it is risky to read too much into a single datum point, the SRC-II registered a NOx emission level of 175 to 300, compared to the 400 to 420 ppm proposed standard for coal derived liquids.

TABLE 110. COMPARISON OF COMBUSTION EMISSIONS TO STANDARDS FOR LIQUID FOSSIL FUEL-FIRED STEAM GENERATORS

			Emissions from Combustion Test	
Contaminant	Existing Standards for Liquid Fossil Fuel	Proposed Standards for Coal Derived Liquid Fuel	Liquid SRC-II	No. 6 petroleum Residual Oil
SO_x	0.8 lb/10^6 Btu (340 ng/J)			
NO_x	0.3 lb/10^6 Btu (130 ng/J) (230 ppm)	0.5 lb/10^6 Btu (217 ng/J) (400-420 ppm)	175-300 ppm	100-160 ppm
Particulates	0.1 lb/10^6 Btu (43 ng/J)		0.015-0.025 ppm	higher than SRC-II
Unburned hydrocarbons			3 ppm	
Carbon monoxide			50 ppm	
Sulfur trioxide			1 ppm	

Other emissions were low. Particulate emissions measured at 0.015 to 0.025 ppm, lower than for oil. No particulate removal equipment was operated during the combustion test. Unburned hydrocarbons measured at less than three ppm (actually the threshold of the monitoring equipment); carbon monoxide was less than 50 ppm; sulfur trioxide less than one ppm.

5.5.4 Evaluation of Unregulated Toxic Substances and Bioassay Results

5.5.4.1 Potential Degree of Hazard of Unregulated Toxic Substances

Analyses of SRC product and by-products has been summarized in Section 3.0. Filby and co-workers (45) of Washington State University conducted studies of the trace element distribution and fate in the SRC-I process. Their data forms the basis of the inorganic product composition and SAM/IA potential degree of hazard tables. Fruchter and Petersen of Battelle Northwest Laboratories, have conducted a program to characterize SRC products, by-products and effluents. Their analyses have been performed primarily on samples derived from the SRC-I process with limited analyses of SRC-II samples. SRC-II samples were used in a recent Level I sampling and analysis study by Hittman Associates. The nature of the methodology used does, however, restrict this preliminary data to qualitative/semi-quantitative interpretation.

5.5.4.1.1 Inorganic Analysis

5.5.4.1.1.1 SRC-I Partitioning Factors and SAM/IA Analysis

Composition of various product and by-product streams is known to vary with the composition of the feed coal. An estimate of the concentration of the inorganic constituent in the naphtha, wash solvent, heavy oil, SRC-I, filter cake, and sulfur is presented in Tables 111 to 115. The tables are based largely on the data generated by Washington State University (45) with incorporation of Battelle Northwest data. The elements having a potential degree of hazard greater than (1) (indicating that the component may be an environmental hazard) are indicated by a (*).

5.5.4.1.1.2 SRC-II Level 1 Methodology and SAM/IA Analysis

Hittman Associates has completed preliminary characteristics of several SRC-II product and by-product streams according to Level 1 methodology. The SAM/IA methodology was utilized by HAI to assess the relative hazard of three product streams (naphtha, middle and heavy distillates) and residue. Although the SAM/IA model is intended to be used as a hazard assessment of discharged streams, the model can be a useful indication of the types of compounds which warrant concern in the event of a spill or as a result of fugitive emissions and leaks from product storage. A summary of the SAM/IA worksheets of the spark source data for these streams is shown in Table 116. The results of the SAM/IA model indicate the expected trend for trace element toxic unit discharge rates for these four streams:

Residue > heavy distillates > middle distillates > naphtha

TABLE 111. ESTIMATED CONCENTRATIONS OF INORGANICS IN SRC-I LIGHT OIL NAPHTHA

Name	SAM/IA Analysis Potential Degree of Hazard[a] Health Based	 Ecological Based
Aluminum	0.75(1.0*)	6.0*(83.*)
Antimony	0.032(0.073)	1.2*(2.8*)
Arsenic	0.19(0.60)	0.94(3.0*)
Barium	8.0(16)x10^{-4}	0.0016(0.0032)
Bromine		
Calcium	0.75(1.6*)	11.*(24.*)
Cerium	6.5(9.1)x10^{-6}	
Cesium	1.2(2.0)x10^{-9}	
Chlorine	0.32(0.54)	
Chromium	0.60(1.4*)	
Cobalt	0.0043(0.010)	0.013(0.031)
Copper	0.050(0.14)	5.0*(14.*)
Europium		
Gallium	8.9(13.5)x10^{-5}	
Hafnium	5.3(7.9)x10^{-5}	
Iron	6.7*(15.*)	40.*(92.*)
Lanthanum	1.6(2.6)x10^{-5}	
Lead	5.6*(28.*)	28*(142*)
Magnesium	ca.0.081(0.20)	ca.0.084(0.21)
Manganese	0.68(2.6*)	1.7*(6.5*)
Mercury	0.79(3.9*)	0.032(0.16)
Nickel	0.65(4.2*)	15.*(97.*)
Potassium	1.2*(2.5*)	1.5*(3.3*)
Rubidium	1.6(5.6)x10^{-4}	
Samarium	1.9(33)x10^{-5}	
Scandium	2.5(4.2)x10^{-6}	
Selenium	3.0*(7.6*)	6.0*(15.*)
Sodium	0.010(0.054)	
Strontium	0.035(0.074)	
Tantalum	9.3(12.8)x10^{-9}	
Terbium		
Thorium	3.7(7.9)x10^{-4}	
Titanium	0.019(0.040)	6.3*(13.*)
Vanadium	0.14(0.28)	2.4*(4.7*)
Zinc	0.14(1.7*)	35.*(420.*)
Zirconium	9.1(17.6)x10^{-4}	

[a] Numbers in parentheses based on maximum, other numbers are based on average. Only the average numbers are included in the SAM/IA analysis summary in Section 5.0.

*A potential degree of hazard greater than one (1) indicates that this component may be an environmental hazard.

SAM/IA Analysis[a]

Stream flow rate: Q = 7.6851/sec
(assuming specific gravity of 0.875)

Stream Potential Degree of Hazard

Health Mate Based 22(72)
Ecological mate Based 215(920)

Number of Entries Compared to Mates

Health 33
Ecological 18

Potential Toxic Unit Discharge Rate Sum

Health Mate Based 170(560)
Ecological Mate Based 1650(7100)

TABLE 112. ESTIMATED INORGANIC CONCENTRATIONS IN SRC-I WASH SOLVENT

	SAM/IA Analysis Potential Degree of Hazard[a]	
Name	Health Based	Ecological Based
Aluminum	0.21(0.29)	17.*(24.*)
Antimony	1.1(2.5)$\times 10^{-4}$	0.0040(0.0094)
Arsenic	0.016(0.051)	0.082(0.26)
Barium	0.21(0.42)	0.42(0.85)
Bromine		
Calcium	0.42(0.92)	6.4(14)
Cerium	3.2(5.4)$\times 10^{-4}$	
Cesium	9.4(15.5)$\times 10^{-10}$	
Chlorine	0.13(0.22)	
Chromium	0.082(0.20)	0.082(0.20)
Cobalt	0.041(0.10)	0.12(0.30)
Copper	0.0075(0.020)	0.75(2.0*)
Europium		
Gallium	5.1(8.0)$\times 10^{-4}$	
Hafnium	4.6(6.8)$\times 10^{-4}$	
Iron	2.5*(5.6*)	15*(34*)
Lanthanum	2.3(3.6)$\times 10^{-6}$	
Magnesium	0.053(0.13)	0.055(0.14)
Manganese	0.68(2.6*)	1.7*(6.5*)
Mercury	3.7*(18.*)	0.15(0.72)
Nickel	1.4*(8.9*)	32*(204*)
Potassium	0.79(1.7*)	1.0*(2.2*)
Rubidium	2.8(9.9)$\times 10^{-5}$	
Samarium	4.3(7.3)$\times 10^{-6}$	
Scandium	2.6(4.4)$\times 10^{-7}$	
Selenium	0.19(0.48)	0.37(0.95)
Sodium	0.0057(0.030)	
Strontium	0.015(0.031)	
Tantalum	6.2(8.6)$\times 10^{-9}$	
Terbium		
Thorium	3.2(6.8)$\times 10^{-4}$	
Titanium	0.014(0.031)	4.7*(10.4*)
Vanadium	0.058(0.11)	0.96(1.9)
Zirconium	0.0010(0.0020)	

[a] Numbers in parentheses based on maximum, other numbers are based on average. Only the average numbers are included in the SAM/IA analysis summary in Section 5.0.

*A potential degree of hazard greater than one (1) indicates that this component may be an environmental hazard.

SAM/IA Analysis[a]

Stream flow rate: Q = 27.67[b] l/sec

Stream Potential Degree of Hazard

Health Mate Based 11(40)
Ecological Mate Based 81 (300

Number of Entries Compared to Mates

Health 31
Ecological 17

Potential Toxic Unit Discharge Rate Sum

Health Mate Based 290 (1100)
Ecological Mate Based 2250 (8300)

TABLE 113. ESTIMATED INORGANIC CONCENTRATIONS IN SRC-I HEAVY OIL

	SAM/IA Analysis Potential Degree of Hazard[a]	
Name	Health Based	Ecological Based
Arsenic	0.88(2.8*)	4.4*(14.*)
Bromine		
Calcium	4.6*(10.4*)	69.*(160.*)
Chromium	24.*(60.*)	24.*(60.*)
Copper	0.20(0.54)	20.*(54.*)
Iron	307.*(667*)	1840*(4000*)
Lead	4.8*(25*)	24*(124*)
Manganese	4.4*(17*)	11.*(43.*)
Nickel	18.*(110.*)	410*(2600*)
Potassium	4.3*(9.0*)	5.7*(11.7*)
Ribidium	2.7(9.4)x10^{-4}	
Selenium	6.9*(18*)	14*(36*)
Strontium	0.043(0.096)	
Titanium	0.34(0.73)	110.*(240.*)
Vanadium	4.4*(8.0*)	73*(130*)
Zinc	0.35(4.4*)	88*(1100*)

[a] Numbers in parenthesis based on maximum, other numbers based on average. Only the average numbers are included in the SAM/IA analysis summary in Section 5.0.

*A potential degree of hazard greater than one (1) indicates that this component may be an environmental hazard.

SAM/IA Analysis[a]

Stream Flow Rate: Q = 30 liters/sec (assuming specific gravity of 1.0).

Stream Potential Degree of Hazard

Health Mate Based 380(940)
Ecological Mate Based 27000 (8600)

Number of Entries Compared to Mates

Health 15
Ecological 13

Potential Toxic Unit Discharge Rate Sum

Health Mate Based 1100 (28000)
Ecological Mate Based 81000 (260000)

TABLE 114. ESTIMATED INORGANIC CONCENTRATIONS IN SRC-I FILTER CAKE

Name	SAM/IA Analysis Potential Degree of Hazard[a] Health Based	Ecological Based
Antimony	0.0031(0.0070)	0.115(0.26)
Arsenic	0.46(1.5*)	2.3*(7.4*)
Barium	0.68(1.4*)	1.4*(2.7*)
Bromine		
Cerium	$4.5(6.4)\times10^{-4}$	
Cesium	$1.5(2.5)\times10^{-5}$	
Chromium	0.94(2.2*)	0.94(2.2*)
Cobalt	0.20(0.50)	0.60(1.5*)
Europium		
Hafnium	0.13(0.020)	
Iron	140*(320*)	860*(1920*)
Lanthanum	$3.2(4.7)\times10^{-5}$	1.3*(2.9*)
Lutetium		
Nickel	0.98(6.2*)	22.*(140.*)
Potassium	1.0*(2.2*)	1.3*(2.9*)
Rubidium	$2.5(8.9)\times10^{-4}$	
Samarium	$3.1(5.3)\times10^{-5}$	
Scandium	$5.2(8.8)\times10^{-5}$	
Selenium	1.2*(3.1*)	2.4*(6.2*)
Sodium	0.035(0.18)	
Strontium	0.027(0.059)	
Tantalum	$3.3(4.6)\times10^{-5}$	
Terbium		
Thorium	0.10(0.21)	
Uranium	$5.2(19)\times10^{-4}$	0.062(0.23)
Zirconium	0.093(0.18)	

[a] Numbers in parenthesis based on maximum, other numbers based on average. Only the average numbers are included in the SAM/IA analysis summary in Section 5.0.

*A potential degree of hazard greater than one (1) indicates that this component may be an environmental hazard.

SAM/IA Analysis[a]

Stream Flow Rate: Q = 53,000 g/sec.

Stream Potential Degree of Hazard

Health Mate Based 150. (340.)
Ecological Mate Based 890. (2100.)

Number of Entries Compared to Mates

Health 22
Ecological 10

Potential Toxic Unit Discharge Rate Sum

Health Mate Based 7.9×10^{6} to 1.79×10^{7}
Ecological Mate Based 4.7×10^{7} to 1.10×10^{8}

TABLE 115. ESTIMATED INORGANIC CONCENTRATIONS IN SRC SULFUR BY-PRODUCT

Name	SAM/IA Analysis Potential Degree of Hazard[a] Health Based	Ecological Based
Aluminum	$4.2(<5.9)x10^{-4}$	0.034(0.047)
Antimony	$1.3(<3.3)x10^{-4}$	0.0050(0.0125)
Arsenic	0.034(<0.11)	0.17(0.56)
Barium	0.18(0.36)	0.36(0.73)
Bromine		
Calcium	0.29(0.65)	4.4*(9.7*)
Cerium	$1.5(2.2)x10^{-5}$	
Cesium	$1.2(2.1)x10^{-5}$	
Chlorine	$5.8(10)x10^{-4}$	
Chromium	0.048(0.11)	0.048(0.11)
Cobalt	1.3*(3.1*)	3.8*(9.4*)
Copper	$6.4(17)x10^{-4}$	0.064(0.17)
Europium		
Gallium	$1.2(1.9)x10^{-4}$	
Hafnium	0.0021(0.0031)	
Iron	2.4*(5.5*)	15*(33*)
Lanthanum	$6.8(11)x10^{-6}$	
Magnesium	0.016(0.041)	0.017(0.043)
Manganese	0.17(0.66)	0.43(1.6*)
Mercury	0.10(0.50)	0.0042(0.020)
Praseodymium		
Ruthenium		
Samarium	$2.2(3.8)x10^{-6}$	
Scandium	$1.8(2.9)x10^{-7}$	
Selenium	0.30(0.78)	0.6(1.6*)
Sodium	0.29(1.4*)	
Strontium	0.0066(0.014)	
Tantalum	$2.3(3.1)x10^{-5}$	
Terbium		
Thorium	0.0035(0.0075)	
Titanium	0.005(0.011)	0.56(1.2*)
Vanadium	0.014(0.028)	0.23(0.47)
Zirconium	0.037(0.073)	

[a] Numbers in parenthesis based on maximum, other numbers based on average. Only the average numbers are included in the SAM/IA analysis summary in Section 5.0.

*A potential degree of hazard greater than one (1) indicates that this component may be an environmental hazard.

SAM/IA Analysis[a]

Stream flow rate: Q = 5127 g/sec.

Stream Potential Degree of Hazard

Health Mate Based 5.2-13.4
Ecological Mate Based 25.5-58.7

Number of Entries Compared to MATE

Health 28
Ecological 15

Potential Toxic Unit Discharge Rate Sum

Health Mate Based 2.7 to 6.9×10^{4}
Ecological Mate Based 1.3 to 3.0×10^{5}

TABLE 116. SUMMARY DERIVED FROM SAM/IA METHODOLOGY APPLIED TO SPARK SOURCE RESULTS FROM PRODUCT STREAMS AND RESIDUE

	Naphtha	Middle distillate	Heavy distillate	Residue
Effluent stream potential degree of hazard				
• Health based MATE	0.15	0.15	30.	40.
• Number of MATEs exceeded	0/19(0%)	0/20(0%)	4/47(4%)	2/47(4%)
• Ecological based MATE	108	51.0	5032	14,288
• Number of MATEs exceeded	1/12(8%)	1/13(7.6%)	7/23(30%)	12/24(50%)
Potential toxic unit discharge rate sum				
• Health based MATE	0.003	0.008	1	5900
• Ecological based	2.5	2.83	154	20.8×10^5

The level of trace elements found in the naphtha and middle distillates were low in comparison with those in the heavy distillates. None of the trace elements examined, and only aluminum in the naphtha and phosphorus (which may be phosphate) in the middle distillates, exceeded their respective health MATE values. The concentration of aluminum and phosphorus in these product streams requires further verification in a Level 2 analysis. For the heavy distillates many trace elements exceeded the ecological MATE values with some elements such as chromium, manganese and silica exceeding both the health and ecological values, as shown in Table 117. Further efforts should be made to accurately quantify these trace elements.

As is expected the residue is the sink for most nonvolatile trace elements. Application of the SAM/IA model for the residue, indicates that several trace elements exceed

TABLE 117. TRACE ELEMENTS EXCEEDING HEALTH OR ECOLOGICAL MATE CONCENTRATIONS IN THE HEAVY DISTILLATES

Aluminum	E*
Cadmium	E
Chromium	H,E
Copper	E
Iron	H
Manganese	H,E
Nickel	E
Phosphorus	E
Silicon	H,E
Vanadium	E
Zinc	E

*E = indicates ecological MATE was exceeded
H = indicates that health MATE was exceeded

health and/or ecological MATE values, where such values exist. The MATE's applied to the residue were for solid waste and as such were much more lax than MATE's used for the product streams.

5.5.4.1.2 Organics Analysis

5.5.4.1.2.1 SRC-II Level 1 Methodology and SAM/IA Analysis

The diversity of organic compounds which can comprise the product streams from a liquefaction system preclude complete identification without years of research. It has been estimated that only 10 percent of the possible compounds in hydrogenation products have been identified and that those compounds found in the MEG's represent even a smaller percentage.

Hittman Associates' Level 1 analysis of the SRC-II product streams was intended to show relative distribution of broad classes of compounds and to determine for the middle and heavy distillates concentration estimates for those organic classes present in highest concentrations.

The SAM/IA model was applied to the middle and heavy distillates. Because of numerous short-comings inherent in MEGs, SAM/IA analysis, and Level 1 methodology, the application of the MEG's is only intended to point out the most highly toxic stream components. The SAM/IA analysis is summarized in Table 118.

TABLE 118. SUMMARY OF SAM/IA FOR MIDDLE AND HEAVY DISTILLATES

"Effluent Stream Potential Degree of Hazard"	Middle distillates	Heavy distillates
• Health based MATE number of MATEs exceeded	2.16×10^8 22/25(88%)	6.13×10^6 38/39(97%)
• Ecological Based MATE number of MATEs exceeded	2.26×10^6 13/13(100%)	1.9×10^5 9/10(90%)
"Potential Toxic Unit Discharge Rate Sum"		
• Health based MATE	1.2×10^7	1.9×10^5
• Ecological based MATE	1.3×10^5	5.2×10^3

The higher effluent stream potential degree of hazard for the middle distillates is based on the health and ecological MATEs of the results of the high concentrations of phenolic compounds in Fractions 5 and 6. The lower effluent stream potential degree of hazard based on ecological MATEs for the heavy distillates is unexpected. The serious ecological hazard presented by the large aromatic concentration in the heavy distillates cannot be appreciated by comparison with the MEGs at this time because ecological MATEs are largely unestablished.

The concentration of various organic constituents identified in samples of SRC-I light oil, wash solvent, and process solvent (a set of progressively higher boiling cuts) are shown in Section 3.0, along with analyses of particulate samples collected directly over the molten product.

5.5.4.2 Potential Ecological and Health Effects of Unregulated Toxic Substances

Although still in the early stages, a program for the toxicological evaluation of various materials associated with the Solvent Refined Coal process has been devised and is underway at the Fort Lewis pilot plant. The principal objective of the program is to evaluate potential health hazards to plant personnel, transporters, and users of SRC materials.

There are three major parts to the program: (1) acute tests to provide guidance for dose levels for the longer term tests and to provide some insight into the effects of short term exposures such as might occur in spills or accidents; (2) inhalation and demand carcinogenesis surveys to evaluate the potential skin and respiratory cancer associated with long term exposures to SRC materials; and (3) subacute and special intermediate tests to evaluate potential teratogenica and other effects.

The only work completed so far are pilot studies to determine appropriate dose size for future studies and the acute inhalation study by vapor phase exposure. No formal reports have been issued as yet by the subcontractor.

5.5.4.2.1 Hazards of Product Oil

Although assessment of the potential health or ecological hazard of spills can be approached in terms of the sum of the hazards of the individual product constituents, a much more realistic approach is to look at the potential hazards of the product as a whole. The intricacies of synergistic and antagonistic interactions of individual components are far from being understood at this time. In assessing the hazards of SRC product, data utilized includes bioassay studies, studies of the effects and hazards of similar fossil fuel substances (e.g., coal, tar and petroleum) and epidemiological studies of similar industries.

Although SRC carcinogenicity studies have not been completed, studies have been performed utilizing other liquefaction product oil. Several streams and products of the coal-hydrogenation process were painted on the skin of mice to test their carcinogenic effect. The light oil stream and eight separate fractions of this stream were all without tumorigenic action. The light and heavy-oil products were mildly tumorigenic, producing predominantely papillomas. However, the streams boiling at high temperatures, the middle oil, light-oil stream residue, pasting oil, and pitch products were all highly carcinogenic. The degree of carcinogenicity increased and the length of the median latent periods decreased as the boiling points rose. The median tumor- or cancer-latent period is the time necessary to reach a 50 percent tumor or cancer index. Tumor induction periods were only slightly delayed by dilution of the pasting oil, application of barrier creams, or application of various washing methods (133).

Observations at a large scale coal liquefaction pilot plant at Institute, West Virginia, indicated that workers were exposed to a significant risk of cancer. Few of the preventive measures commonly practiced in industry today, such as programs to promote worker hygiene and protective clothing, had been developed at the time of the West Virginia pilot plant operations. The risk of cancer to workers at present day coal liquefaction facilities is minimized by exercising the necessary precautions. The incidence of skin cancer in workmen exposed to the coal hydrogenation process was between 16 and 37 times greater than that of West Virginia or the entire United States. Benzo(a)pyrene deposits on the skin of workers could often be traced to exposure to high concentrations of airborne oil fumes. Analysis of air samples for benzo(a)pyrene indicated that pitch treatment or solids removal operations contributed significantly to airborne contamination. Maintenance and repair operations often resulted in direct dermal contact with carcinogenic materials (134).

Insight into the potential carcinogenic hazard of coal liquefaction processes can be gained by examining hazards present in similar industries such as by-product coking. There are, however, significant differences between these processes and these differences can drastically affect the carcinogenicity of the fuel products. Briefly, coal tars consist of volatiles driven off coal which has been heated to very high temperatures (1000° to 1500°C) in the absence of air. By comparison, liquefaction processes utilize relatively low temperatures (less than 500°C), high pressures (2000 to 4000 psig) and a hydrogen enriched atmosphere.

The carcinogenic potential of coal tars and coke oven emissions has been extensively studied and documented. Workers exposed to high levels of coal volatiles showed an increased incidence to skin and lung cancers. Such studies raise concern over the potential hazard of the coal liquefaction process. The indications are, however, that the higher temperatures utilized in the coking industry produce a more potentially carcinogenic environment than does the SRC process. Further studies could assess more fully the relative hazards of the two processes and their respective fuel products.

At times of spills or in workplace situations it is imperative that hazard of skin contact with SRC product be greatly emphasized. During SRC pilot plant, operations, toxic exposure has been limited to accidental skin contact. A worker suffered a case of skin burn on the hand (redness, vesiculation and ulceration of the skin) when he was moving a barrel containing a hydrocarbon liquid and some spilled on his hand. Subsequent analysis of the hydrocarbon liquid showed it contained 6.7 percent phenol, 4.4 percent of o-cresol, 13 percent m-cresol, and 3.5 percent p-cresol (135).

In summary, the toxicity and carcinogenic potential of SRC products is recognized. However, since little is known on the extent of this hazard, various studies have been initiated and are in progress to provide appropriate data from which a reasonable assessment can be made of the hazard.

The potential hazard of SRC products is difficult to assess because of the incomplete status of SRC toxicity and carcinogenic studies. Also, quantitative analyses of SRC-II product has also not been completed

In the absence of medical data, organic compounds with boiling points above 250°C should be handled with caution. In general, these are the compounds with the higher molecular weights, larger number of aromatic rings, lower water solubility and higher potential for relative persistence and bioaccumulation in organisms (136).

The environmental hazard of a spill of SRC product would at least equal, and in all likelihood, exceed that created by a spill of a similar petroleum oil. The SRC product is suggested to be more carcinogenic than petroleum oils, although this has not yet been verified by laboratory studies. The hazard of skin contact should be greatly emphasized during clean-up of any spill as well as during SRC production and transporting.

The environmental effects of toxic organics in coal liquefaction products and high-boiling, carbon-containing residues represent the area of greatest estimated concern. Quantitative definition of the presence and effects of these materials on workplace personnel, other impacted personnel, and the ambient environment is essential.

5.5.4.2.2 Hazards of Known Constituents in SRC Products

The constituents in coal liquefaction product oil are known to be carcinogenic. Analysis of product oil from coal liquefaction, as well as oils in coal tar and petroleum crudes, have revealed high levels of PAH compounds. Benzo(a)pyrene concentrations ranged from 40 to 50 ppm in coal-derived products. The concentration in mg/l of PAH in a liquefaction oil product similar to SRC (Synthoil) was: phenanthrene 413, benzo(a)antracene 18, and benzo(a)pyrene 41. These levels greatly exceed recommended MATE levels. For example, the air, water, and land MATE values for benzo(a)pyrene are respectively, 0.02, 0.3 and 0.6 μg/l (39).

Aromatic hydrocarbons are highly lipophilic and readily penetrate into cells. Repeated topical application of PAH dissolved in solvent to the skin of mice and rabbits caused systemic effects, indicating that the PAH are absorbed precutaneously. Pathological changes were observed in the blood, spleen, lymph nodes, and bone marrow (137).

SRC product constituents are found in various waste streams. Discussion of these constituents has been covered under sections 5.2.3, 5.3.3, and 5.4.3.

5.5.4.2.3 SRC Toxicity Studies

As discussed in Section 3.0, a toxicological evaluation of various materials associated with the SRC process has been devised and is presently underway. Only pilot studies and the acute inhalation study by vapor phase exposure have been completed. No formal reports have been issued as yet by the subcontractor.

Initial exposures to the skin painting produced substantial mortality among those mice exposed to with light oil, wash solvent, and wet mineral residue, containing about 50 percent wash solvent. The probable cause of the mortality experience is believed to be systematic phenolic poisoning caused by the relatively high concentrations of phenolic components in those test materials.

A pilot study was then performed to determine appropriate dose levels for the two-year skin painting study. Results indicated that dose levels approximately one-third those originally used would be adequately tolerated. Upon sacrifice, a substantial number of the animals from the pilot study, including control, exhibited corneal capacity. The causative agent, if any, was uncertain; but, if it was a chemical agent, it was apparently transmitted from cage to cage in the vapor phase. A 30-day subacute inhalation study is to be performed to determine if the corneal opacity was caused by the test materials.

5.5.4.2.4 Other Liquefaction Toxicity Studies

Although the SRC toxicity program has not been completed, laboratory study results are available of the effects of product oils from other hydrogenation processes. Experimental studies were performed on Bergius oils and Fischer-Tropsch oils obtained from the experimental coal hydrogenation-liquefaction operation of the U.S. Bureau of Mines at Bruceton, Pennsylvania. All fractions were tested for carcinogencity by repeated application to the skin of mice and rabbits and by intramuscular injection into the thighs of rats. Eight of the nine fractions of the Bergius oil fractionation products were carcinogenic with the degree of carcinogenic potency generally increasing with increasing boiling point. Fischer-Tropsch synthesis products were less carcinogenic than Bergius products and appeared to have a narrower speces and tissues susceptibility spectrum than the latter (44).

5.6 Radiation and Noise Impacts

Heat, noise, and radioactivity are among the class of pollutants sometimes labeled as nonchemical pollutants (39). Factors determinant to the impacts of radiation and noise, as with other pollutants, include, in part, the intensity or level of the emission, the air dispersion features at specific sites, the duration of the exposure, and the distance between the point source(s) and the receptor(s). Therefore, until commercial-sized SRC liquefaction plants are built at specific sites, the precise impacts of heat loss, noise, and the release of radionuclides from the various process modules cannot be determined in a quantitative sense; sources of these pollutants were discussed in a previous report (45).

5.6.1 Radioactivity

Concern over the potential extent and effect of radioactivity emitted during the operation of a commercial-sized SRC liquefaction plant is of recent origin. Approximately 290 mCi of radiation would be associated with the 28,123 Mg of Illinois No. 6 coal consumed daily by a hypothetical commercial SRC plant (41). In an earlier report (41), treated emission streams of coal dust (the largest potential source of particulate radioactivity) associated with a hypothetical synfuels facility using 28,123 mg Illinois No. 6 coal per day were shown to contain between 0.9 and 167 Mg dust/m^3; this amount of dust corresponded to between 9.28×10^{-12} to 1.72×10^{-9} Ci/m^3. Of these values, from 4.77×10^{-16} to 8.85×10^{-14} Ci/m^3 was associated with the decay of each isotope of the U^{238} series; 2.2×10^{-17} to 4.1×10^{-15} Ci/m^3 with each isotope of the U^{235} series, and 2.2×10^{-16} to 4.1×10^{-14} Ci/m^3 with each isotope of the Th^{232} series (47). The potential health effects associated with this amount of radioactivity are discussed further in Section 5.6.4.1.

5.6.2 Noise

Noise impacts can arise during both the construction and operation of the SRC liquefaction plant. Noise, irrespective of its source, can exert localized, short-range impacts on receptors, generally not extending more than a radius of a few kilometers beyond the plant and the auxiliary facilities. Sources of noise in operating SRC plants have been reported elsewhere (41).

The noise generated by heavy construction equipment is generally at the level of 80 to 100 decibels dB(A) at a distance of about 15 meters; at a distance of about 600 meters from the operating equipment, the noise level usually falls to 60 to 80 dB(A) and would be in compliance with noise standards although still noticeable to human ears (138). Blasting operations would superimpose a short-term spike on the construction equipment noise levels and would be perceptible at greater distances (138).

Noise generated inside a coal liquefaction plant must be kept in compliance with federal regulations (i.e., at or below 90 dB(A)) under the Occupational Safety and Health Act (OSHA) 1970. The highest noise levels within the plant area will emanate from the coal shaker, reaching 110 to 125 dB(A) at a distance of about three meters (78); these levels exceed the OSHA limit set at 90 dB(A). Other important noise emitters in the plant area, include the following (41):

- Dust collector
- Primary coal crusher
- Secondary coal crusher

Within the SRC plant, per se, potentially high noise levels of varying frequencies emanate from process heaters and boilers, compressors, high pressure let-down valves and reciprocating pumps; these sources would be expected to emit noise at between 90 to 100 dB(A) (74). Mitigation of noise levels at specific points inside the SRC plant, per se, could be accomplished after the noise-level contours have been established therein by (138):

- Installing mufflers where applicable
- Enclosing or insulating motor cases
- Insulating operating stations
- Adding insulated ducts or mufflers to boiler burners
- Monitoring for noise so as to establish new areas requiring further equipment relocation or insulation (138).

5.6.3 Thermal Factors

The thermal efficiency of the SRC liquefaction process (SRC-II) base design is estimated to be about 74 percent, based on the assumption that the SRC-mineral residue is not further treated to recover excess energy (41). If one further assumes that the heating value of the feed coal (i.e., about 21,000 Mg feed coal per day) amounts to 29,822 joules/kg, the heat loss to the external environment would be about 160 x 10^{12} joules per day (43). However, the impacts of such heat losses would be localized and would be expected to moify local rainfall patterns and snowmelt, particularly in the arid and semi-arid portions of EPA Regions VIII and IX (Four Corners and Fort Union Regions) of the United States. Relatively simple approaches to the mitigation of these negative impacts would include: (1) use of the waste heat for coal drying or other uses; (2) optimization of heat balance when practicable; (3) increased water reuse; and (4) increased heat recovery by use of more heat exchangers (41).

5.6.4 Potential Ecological and Health Effects of Radiation, Noise, and Thermal Emissions

5.6.4.1 Radiation

The potential for various radioactive emissions to cause biological damage is determined, in part, by: the capacity of the particles (alpha, beta, or gamma) to penetrate tissue; the frequency and amount of isotope ingested via food, water, or inhalation intakes; distance of receptor from the sources; duration of exposure; the effective dose, and the dose rate.

Permissible exposure limits for the workplace and the general population are shown in Table 119. On the basis of present knowledge (43), it appears that dust from Illinois No. 6 coal (100 mg coal dust/m^3/8 hr. day) would, if inhaled, not represent a hazard to workers in SRC plants. Some uncertainty remains, however, in that it is not certain that radionuclide enrichment on small aerosols can be ruled out. However, it is important to remember that the general U.S. population is exposed annually to natural radiation at a whole body dose ranging from 0.1 to 0.4 rem; this exposure is judged not to require the monitoring of individuals (139). Radiological monitoring programs ongoing at the federal and state levels were discussed in an earlier report (41).

In each one of the three natural radioactive series, there is a gaseous alpha particle emitter. Each of these gases is an isotope of the element having the atomic number 86, usually called radon. The gases are: Rn^{219} (actinon), Rn^{220} (thoron), and Rn^{222} (radon). Radon is chemically inert; hence, no gas mask can separate if from the air

TABLE 119. RADIATION PROTECTION GUIDES (43)

Type of Exposure	Length of Exposure	Dose (rem)
Radiation worker:		
(a) Whole body, head and trunk, active blood-forming organs, gonads, or lens of eye	Accumulated dose	5 times number of years beyond age 18
	13 weeks	3
(b) Skin of whole body and thyroid	Year	30
	13 weeks	10
(c) Hands and forearms, feet, and ankles	Year	75
	13 weeks	25
(d) Bone	Body burden	0.1 μCi of Ra^{226} or its biological equivalent
(e) Other organs	Year	15
	13 weeks	5
Population:		
(a) Individual (adult male)	Year	0.5 (whole body)
(b) Average	30 years	5 (gonads)

chemically. Once it enters the lungs, this gas is very destructive, since it is literally present within a vital organ. The maximum permissible safe concentration of radon in the atmosphere is about 10^{-15} percent by volume (140). From the projections of the thorium and uranium levels in coal, and further by assuming that the steady state condition exists, the amount of radon associated with a given amount of coal can be calculated. These calculations have been performed for 28,123 Mg of the most radioactive coal known in the United States, as shown in Table 120. The estimated concentration of uranium and thorium due to the dust from coal preparation at an SRC facility using Illinois No. 6 coal was reported to range between 0.091 to 1.4 and 0.12 to 1.9 $\mu g/m^3$, respectively. The corresponding values, using the most radioactive known coal in the United States, are: 0.46 to 7.1 μg uranium/m^3, and 0.53 to 8.3 μg thorium/m^3. The concentrations of radon which correspond to these figures are: 1. to 15. x 10^{-18}g Rn^{222}; 5 to 81 x 10^{-26}g Rn^{219}, and 6 to 99 x 10^{-23}g Rn^{220} per cubic meter for a maximum total of 1.5 x 10^{-17}g Rn/m^3, or 1.7 x 10^{-25} volume percent. This corresponds to a maximum of 0.0072 ergs/sec/m^3. For a standard (70 kg) man having 0.00566 m^3 lung capacity, the exposure would be 5.8 x 10^{-12} rads or 5.8 x 10^{-11} rems per second when his lungs are filled to capacity. These values are far below the estimated permissible levels established by the radiation protection guidelines shown in Table 119 (43).

As a second estimate, the radiological exposure of a worker breathing coal dust containing radon daughters was calculated, on the assumption that a person doing light work would breathe 28.6 l/min or 13.728 m^3 per eight hours. If one assumes that the air breathed in contains 100 mg coal dust/m^3 and that 50 percent of the coal dust is trapped in

TABLE 120. ESTIMATION OF THE MAXIMUM AMOUNT OF RADON ASSOCIATED WITH 28,123 MG OF THE MOST RADIOACTIVE COAL KNOWN IN THE UNITED STATES

Isotope	Amount	Decay Product	Total Energy (ergs/sec)	Total Decomposition Time (sec.)
Rn^{222}	$4.7x10^{-7}$	alpha	19700.	$2.79x10^{9}$
		gamma	1.8	$2.3x10^{6}$
Rn^{219}	$2.6x10^{-14}$	alpha	1400.	$1.32x10^{8}$
		gamma	12.	$2.4x10^{7}$
Rn^{220}	$3.3x10^{-11}$	alpha	15000.	$1.13x10^{9}$
		gamma	2.9	$3.3x10^{6}$
		Total ergs/sec produced:	37000.	

the lung, one finds a build-up of coal dust of 1.37 g per day; this calculates to a lung deposit of 350 g per year for a person doing light work on an eight hour day. This assumption is the maximum possible build-up since no coal dust is assumed lost due the normal cleaning processes of the lung. Consideration of the number of disintegrations, the energy of each disintegration, and the relative biological effectiveness of each type of disintegration, leads to the conclusion that a 70 kg (standard) man would be exposed to 2.2 x 10^{-12} or 1.9 x 10^{-11} rem of irradiation/day. Given that the workers should stay with the same job for the total plant lifetime of 30 years, and that 260 days per year were worked, the cumulative exposure would be 5.7 x 10^{-10} rad or 4.9 x 10^{-9} rem. These values are far below the estimated permissible levels established by the Bureau of Radiological Health (1970) shown in Table 120.

5.6.4.2 Noise

Present evidence suggests that although noise could create serious health hazards for exposed workers, there is reason to believe that use of inexpensive measures such as individual hearing protection devices, or the use of equipment design modifications, may resolve most of the potential problems. For optimum results, it would be useful to establish noise-level contours for SRC demonstration plants at the earliest date, whereupon control of plant-connected noises may be brought into conformity with OSHA noise standards.

Another facet of this problem is whether noises emitted at different frequencies and intensities beyond the construction site or the synfuels facility, might have adverse effects on brooding bird cycles, and/or on animal reproduction cycles. Little or no information is available on this problem; however, it is evident that the impacts of noise would be highly localized and that the general response on the part of mammals and birds would be to depart the noisy areas and occupy quieter zones.

5.7 Summary of Major Environmental Impacts

The potential degrees of hazard and toxic unit discharge rates were calculated for many waste streams in a manner similar to that shown for SRC solid residue and gasifier slag in the Appendix. Figures 68 and 69 are the SAM/IA summaries of the estimates (the second form of the SAM/IA analysis) using "Average U.S. Coal." Figure 70 is the SAM/IA summary using "Maximum U.S. Coal" for several discharges, as follows:

Gaseous Emission Stream Number*	Category
101 Suspended particulates	Coal pretreatment
102 Stretford tail gas	Sulfur recovery, required auxiliary process
103 Oxygen generation	Oxygen generation, incidental auxiliary process
104 Flare	Flare, required auxiliary process
105 Boiler flue gas - fly ash	Steam generation, incidental auxiliary process

Aqueous Effluent Stream Number	Category
201 Coal pile drainage	Coal storage, incidental auxiliary process
202 Ash pond effluent	Wastewater treatment incidental auxiliary process
203 Combined treatment facility wastewater	Final wastewater treatment, incidental auxiliary process

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**Stream numbers correspond to the sampling points on Figure 68.*

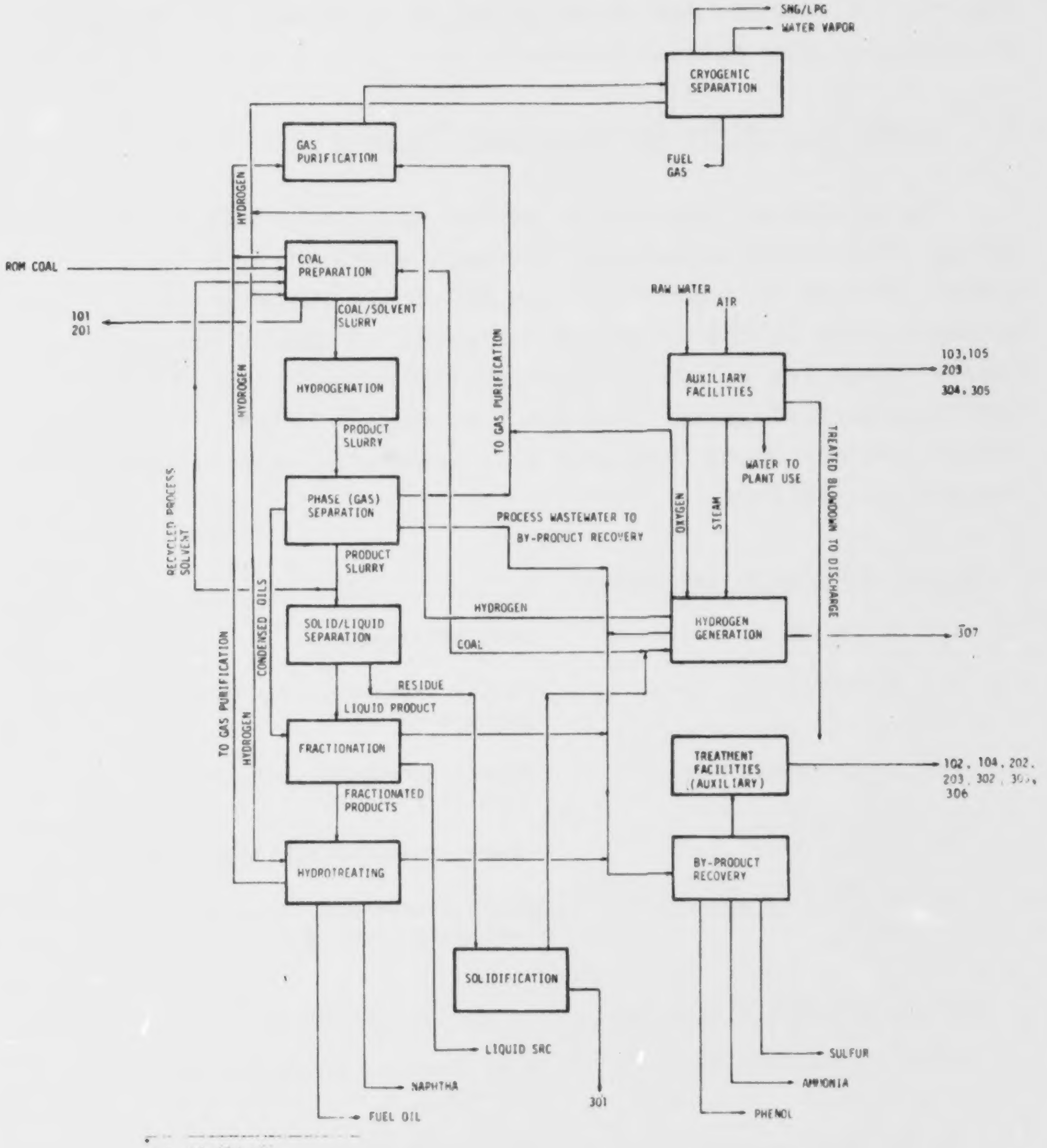

SNG/LPG
WATER VAPOR
CRYOGENIC SEPARATION
FUEL GAS
GAS PURIFICATION
HYDROGEN
ROM COAL
COAL PREPARATION
101
201
COAL/SOLVENT SLURRY
HYDROGENATION
HYDROGEN
PRODUCT SLURRY
TO GAS PURIFICATION
RECYCLED PROCESS SOLVENT
PHASE (GAS) SEPARATION
PROCESS WASTEWATER TO BY-PRODUCT RECOVERY
PRODUCT SLURRY
CONDENSED OILS
SOLID/LIQUID SEPARATION
HYDROGEN
COAL
RESIDUE
LIQUID PRODUCT
TO GAS PURIFICATION
HYDROGEN
FRACTIONATION
FRACTIONATED PRODUCTS
HYDROTREATING
SOLIDIFICATION
LIQUID SRC
NAPHTHA
FUEL OIL
301
RAW WATER
AIR
AUXILIARY FACILITIES
103,105
203
304, 305
WATER TO PLANT USE
OXYGEN
STEAM
TREATED BLOWDOWN TO DISCHARGE
HYDROGEN GENERATION
307
TREATMENT FACILITIES (AUXILIARY)
102, 104, 202, 203, 302, 303, 306
BY-PRODUCT RECOVERY
SULFUR
AMMONIA
PHENOL

Figure 68. Diagrammatic representation of a conceptualized SRC facility showing appropriate stream numbers.

1. SOURCE AND APPLICABLE CONTROL OPTIONS

Conceptualized SRC Facility Using "Average U.S. Coal"

2. PROCESS THROUGHPUT OR CAPACITY 28,000 Mg "Average U.S. Coal"

3. USE THIS SPACE TO SKETCH A BLOCK DIAGRAM OF THE SOURCE AND CONTROL ITEMS SHOWING ALL EFFLUENT STREAMS. INDICATE EACH STREAM WITH A CIRCLED NUMBER USING 101-199 FOR GASEOUS STREAMS, 201-299 FOR LIQUID STREAMS, AND 301-399 FOR SOLID WASTE STREAMS.

See Figure 68

4. LIST AND DESCRIBE GASEOUS EFFLUENT STREAMS USING RELEVANT NUMBERS FROM STEP 3.

101 Suspended particulates from coal preparation
102 Emissions after treatment of Stretford Tail Gas
103 Oxygen Generation
104 Flare
105 Boiler Flue Gas
106
107

5. LIST AND DESCRIBE LIQUID EFFLUENT STREAMS USING RELEVANT NUMBERS FROM STEP 3.

201 Coal Pile Drainage
202 Ash pond effluent
203 Wastewater Treatment Facility
204
205
206

6. LIST AND DESCRIBE SOLID WASTE EFFLUENT STREAMS USING RELEVANT NUMBERS FROM STEP 3.

301 SRC Mineral Residue 307. Gasifier Slag
302 API Separator Bottoms
303 Bio-Unit Sludge
304 Fly Ash (Particulates - Steam Generation)
305 Bottom Ash (Particulates - Steam Generation)
306 Flare K.O. Drum

7. IF YOU ARE PERFORMING A LEVEL 1 ASSESSMENT, COMPLETE THE IA02-LEVEL 1 FORM FOR EACH EFFLUENT STREAM LISTED ABOVE. IF YOU ARE PERFORMING A LEVEL 2 ASSESSMENT, COMPLETE THE IA02-LEVEL 2 FORM FOR EACH EFFLUENT STREAM LISTED ABOVE.

Figure 69. SAM/IA summary using average U.S. coal.

8. LIST SUMS FROM LINE 7, FORMS IA02, IN TABLE BELOW

DEGREE OF HAZARD AND TOXIC UNIT DISCHARGE RATES BY EFFLUENT STREAM

GASEOUS					LIQUID					SOLID WASTE				
STREAM CODE	DEGREE OF HAZARD		TOXIC UNIT DISCHARGE RATES		STREAM CODE	DEGREE OF HAZARD		TOXIC UNIT DISCHARGE RATES		STREAM CODE	DEGREE OF HAZARD		TOXIC UNIT DISCHARGE RATES	
	HEALTH BASED	ECOL BASED	HEALTH BASED	ECOL BASED		HEALTH BASED	ECOL BASED	HEALTH BASED	ECOL BASED		HEALTH BASED	ECOL BASED	HEALTH BASED	ECOL BASED
	—	—	(m^3/sec)			—	—	(l/sec)			—	—	(g/sec)	
101	A*	-	B*	-	201	6500	4.5E4	6500	4.5E4	301	340	2400	1.6E7	1.1E8
102	C*	D*	E*	F*						302	1900	3.9E4	H*	I*
103	0.086		7.5	-	202	G*	-	-	-	303	10	130	72	880
104	134	38	18	5.0	203	427	22	15	0.82	304	300	2500	1.2E4	2.3E5
105	130	0.43	1.4E4	50						305	21	300	1.6E4	2.3E5
										306	12	76	-	-
										307	160	800	1.8E6	8.8E6
A	B	C	D	E	F	G	H	I	J	K	L	M	N	O

9 SUM SEPARATELY GASEOUS, LIQUID AND SOLID WASTE STREAM DEGREES OF HAZARD FROM TABLE AT LINE 8 (I.E., SUM COLUMNS)

	TOTAL DEGREE OF HAZARD	
	HEALTH-BASED	ECOLOGICAL-BASED
GASEOUS	(Σ COL. B) 9A 360-390	(Σ COL. C) 9A' 42-62.
LIQUID	(Σ COL. G) 9B 6.9x10^3	(Σ COL. H) 9B' 4.5x10^4
SOLID WASTE	(Σ COL. L) 9C 2700	(Σ COL. M) 9C' 4.5x10^4

10. SUM SEPARATELY GASEOUS, LIQUID AND SOLID WASTE STREAM TOXIC UNIT DISCHARGE RATES FROM TABLE AT LINE 8 (I.E., SUM COLUMNS)

	TOTAL TOXIC UNIT DISCHARGE RATES	
	HEALTH-BASED	ECOLOGICAL-BASED
GASEOUS (m^3/sec)	(Σ COL. D) 10A 2.1x10^{4}to3.3x10^4	(Σ COL. E) 10A' 380-2100.
LIQUID (l/sec)	(Σ COL. I) 10B 6500	(Σ COL. J) 10B' 4.5x10^4
SOLID WASTE (g/sec)	(Σ COL. N) 10C 1.8x10^7	(Σ COL. O) 10C' 1.2x10^8

11 NUMBER OF EFFLUENT STREAMS

GASEOUS 11A 5

LIQUID 11B 3

SOLID WASTE 11C 7

Figure 69. (continued).

NOTES

1.4E4 equivalent to 1.4×10^4

Footnote	Comment
A*	0.045-30
B*	1.7 to 1.1×10^4
C*	92.-100.
D*	4.0-24.
E*	7600.-8400.
F*	330.-2000.
G*	1.9-5.7
H*	220.-2000.
I*	4500.-4.1×10^4

ASSUMPTIONS

LIST ALL ASSUMPTIONS MADE REGARDING FLOW RATE, EMISSION FACTORS AND MATE VALUES.

Figure 69. (continued).

1. SOURCE AND APPLICABLE CONTROL OPTIONS

Conceptualized SRC Facility Using "Maximum U.S. Coal"

2. PROCESS THROUGHPUT OR CAPACITY 28,000 Mg "Maximum U.S. Coal"

3. USE THIS SPACE TO SKETCH A BLOCK DIAGRAM OF THE SOURCE AND CONTROL ITEMS SHOWING ALL EFFLUENT STREAMS. INDICATE EACH STREAM WITH A CIRCLED NUMBER USING 101-199 FOR GASEOUS STREAMS, 201-299 FOR LIQUID STREAMS, AND 301-399 FOR SOLID WASTE STREAMS.

See Figure 68

4. LIST AND DESCRIBE GASEOUS EFFLUENT STREAMS USING RELEVANT NUMBERS FROM STEP 3.

101 Suspended particulates from coal preparation
102 Emission after treatment of Stretford Tail Gas
103 Oxygen Generation
104 Flare
105 Boiler Flue Gas
106
107

5. LIST AND DESCRIBE LIQUID EFFLUENT STREAMS USING RELEVANT NUMBERS FROM STEP 3.

201 Coal Pile Drainage
202 Ash Pond Effluent
203 Wastewater Treatment Facility
204
205
206

6. LIST AND DESCRIBE SOLID WASTE EFFLUENT STREAMS USING RELEVANT NUMBERS FROM STEP 3.

301 SRC Mineral Residue 307. Gasifier Slag
302 API Separator Bottoms
303 Bio-Unit Sludge
304 Fly Ash
305 Bottom Ash
306 Flare K.O. Drum

Figure 70. SAM/IA summary using maximum U.S. coal.

8. LIST SUMS FROM LINE 7, FORMS IA02, IN TABLE BELOW

DEGREE OF HAZARD AND TOXIC UNIT DISCHARGE RATES BY EFFLUENT STREAM

GASEOUS					LIQUID					SOLID WASTE				
STREAM CODE	DEGREE OF HAZARD		TOXIC UNIT DISCHARGE RATES		STREAM CODE	DEGREE OF HAZARD		TOXIC UNIT DISCHARGE RATES		STREAM CODE	DEGREE OF HAZARD		TOXIC UNIT DISCHARGE RATES	
	HEALTH BASED	ECOL BASED	HEALTH BASED	ECOL BASED		HEALTH BASED	ECOL BASED	HEALTH BASED	ECOL BASED		HEALTH BASED	ECOL BASED	HEALTH BASED	ECOL BASED
	—	—	(m^3/sec)			—	—	(l/sec)			—	—	(g/sec)	
101	A*	-	B*	-	201	6.6E4	4.0E5	6.6E4	4.0E5	301	750	5400	3.5E7	2.5E8
102	C*	D*	E*	F*	202	G*	-	-	-	302	1900	3.9E4	H*	I*
103	0.086	-	7.5	-	203	9.52	40	34	1.5	303	14	200	96	1400
104	134	38	18	5.0						304	700	7300	2.9E5	3.0E6
105	160.	0.43	1.8E4	50						305	21	300	1.6E4	2.3E5
										306	29	190	-	-
										307	830	4900	8.8E6	5.3E7
A	B	C	D	E	F	G	H	I	J	K	L	M	N	O

9. SUM SEPARATELY GASEOUS, LIQUID AND SOLID WASTE STREAM DEGREES OF HAZARD FROM TABLE AT LINE 8 (I.E., SUM COLUMNS)

	TOTAL DEGREE OF HAZARD	
	HEALTH-BASED	ECOLOGICAL-BASED
GASEOUS	(Σ COL. B) 9A 390.-460.	(Σ COL. C) 9A' 42.-62.
LIQUID	(Σ COL. G) 9B 6.7 x 10^4	(Σ COL. H) 9B' 4.0 x 10^5
SOLID WASTE	(Σ COL. L) 9C 4200.	(Σ COL. M) 9C' 5.7 x 10^4

10. SUM SEPARATELY GASEOUS, LIQUID AND SOLID WASTE STREAM TOXIC UNIT DISCHARGE RATES FROM TABLE AT LINE 8 (I.E., SUM COLUMNS)

	TOTAL TOXIC UNIT DISCHARGE RATES	
	HEALTH-BASED	ECOLOGICAL-BASED
GASEOUS (m^3/sec)	(Σ COL. D) 10A 2.6x10^4to5.3x10^4	(Σ COL. E) 10A' 380.-2100.
LIQUID (l/sec)	(Σ COL. I) 10B 6.6x10^4	(Σ COL. J) 10B' 4.0x10^5
SOLID WASTE (g/sec)	(Σ COL. N) 10C 4.4x10^7	(Σ COL. O) 10C' 3.1x10^8

11. NUMBER OF EFFLUENT STREAMS

GASEOUS 11A 5

LIQUID 11B 3

SOLID WASTE 11C 7

12. LIST POLLUTANT SPECIES KNOWN OR SUSPECTED TO BE EMITTED FOR WHICH A MATE IS NOT AVAILABLE

See Section 3.0 of this report.

*See footnote list next page

Figure 70. (continued).

NOTES

1.8 E4 equivalent to 1.8×10^4

Footnote	Comment
A*	0.107 to 70
B*	41. to 2.7×10^4
C*	92.-100.
D*	4.0-24.
E*	7600.-8400.
F*	330.-2000.
G*	1.9-5.7
H*	220.-2000.
I*	$4500-4.1 \times 10^4$

ASSUMPTIONS

LIST ALL ASSUMPTIONS MADE REGARDING FLOW RATE, EMISSION FACTORS AND MATE VALUES.

Figure 70. (continued).

Solid Waste Stream Number	Category
301 SRC mineral residue	Solids/liquids separation process
302 API separator bottoms	Wastewater treatment
303 Bio-Unit sludge	Wastewater treatment
304 Fly ash	Steam generation
305 Bottom ash	Steam generation
306 Flare knock-out drum	Flare
307 Gasifier slag	Hydrogen generation

In general, the health based potential degree of hazard was calculated for more pollutants in more waste streams than was the ecological based degree of hazard. This results directly from the larger number of health-based MATEs available for this calculation. Thus, the potential toxic unit discharge rate sum, which is simply the potential degree of hazards of the individual pollutants in the stream multiplied by the stream flow rate, should give the best relative indication of the individual toxicities of the individual streams. On this basis, the most toxic gaseous waste stream appears to be the boiler flue gas; the most toxic liquid waste stream appears to be the coal pile drainage, and the most toxic solid waste stream appears to be the SRC-mineral residue. The boiler flue gas appears to be: approximately as toxic (from 0.3 to 2 times) as the coal pile drainage; about 1000 to 2000 times less toxic than the SRC-mineral residue; 120 to 490 times less toxic than the gasifier slag; 9 to 16 times less toxic than the fly ash, and approximately as toxic as the bottom ash. Of the wastes specific for liquefaction technology, only the SRC-mineral residue and the gasifier slag are more toxic than the fly ash produced, with the relative toxicities being 120 to 130 and 15 to 30 times as toxic, respectively. Considerable useable energy may be present in SRC-mineral residue which may be extracted using some future technology, but the gasifier slag appears practically useless.

5.7.1 Air Impacts

Present indications are that air emissions during the regular operation of the SRC-II system will arise primarily from the auxiliary processes, several of which are considered incidental to the primary function of the system. Emissions from the processes and the auxiliary processes should be limited to leaks in pump seals, valves, joints, and flanges and from product handling and storage. These processes should be monitored in the workplace as part of the industrial hygiene program.

Other emissions of note, but unquantified and unevaluated by the SAM/IA methodology are:

- Fugitive emissions from sulfur storage (one of the by-products, hence a required auxiliary process)
- Gaseous emissions from the wastewater treatment plant (an incidental auxiliary process)
- Fugitive hydrocarbon emissions from processes such as: hydrogenation (liquefaction); gas separation; solids/liquids separation; fractionation; and hydrotreating

- Fugitive hydrocarbon emissions from required auxiliary processes that include: acid gas removal, cryogenic separation, product storage, sulfur recovery, and unburned hydrocarbons from the flare system

- Fugitive hydrocarbon emissions from: hydrogen generation, and wastewater treatment

- Drift of corrosion inhibitors and antifouling agents from cooling towers (an incidental auxiliary process)

- Emissions associated with the regeneration of catalysts and activated carbon. This regeneration should be done using proper air pollution controls in that the catalysts have a fairly long lifetime (43).

As discussed in Section 5.2.2 and 5.2.3, ammonia, arsenic, barium, beryllium, cadmium, carbon monoxide, carbon dioxide, chromium, copper, fluorides, iron, manganese, nickel, nitrogen oxides, sulfur, and particulates are regulated pollutants which may cause adverse environmental impacts. As discussed in Section 5.2.4, aluminum, anthanthrene, benzo(a)pyrene, lithium, titanium, and vanadium are unregulated pollutants which may cause environmental damage. As discussed in Section 5.1, the most hazardous atmospheric waste stream appears to be the boiler flue gas. In general, atmospheric emissions appear to be less of an environmental hazard than do solid wastes.

5.7.2 Water Impacts

Table 121 shows the pollutants in the individual liquid waste streams which may represent an environmental hazard. The SAM/IA analysis shows that the total hazard expected from aqueous waste streams is about equal to that expected from atmospheric waste streams and is less than that expected from solid waste streams.

5.7.3 Impacts of Solid Wastes

Table 122 indicates which individual pollutants may be a problem in the individual solid waste streams. No applicable solid waste standards or regulations were found so that all of the pollutants shown in these tables are considered "unregulated", however, SRC wastes may be determined to be hazardous wastes under the Resource Recovery and Conservation Act of 1976. The SAM/IA analysis indicates that the SRC-mineral residue and the gasifier slag will represent the greatest environmental hazard. This analysis considers the quantity of the waste streams as well as the composition.

5.7.4 Product Impacts

The potential impact of SRC products has been examined in terms of product toxicity, spills and fire hazards, and the SRC combustion emissions. Federal and state regulations are summarized where applicable.

5.7.4.1 Regulations

SRC product is known to contain toxic and hazardous constituents. There are, however, no toxic substances

TABLE 121. SUMMARY OF INDIVIDUAL POLLUTANTS WHICH MAY BE HAZARDOUS IN THE INDIVIDUAL AQUEOUS WASTE STREAMS FROM THE CONCEPTUALIZED SRC FACILITY

		Waste Streams in Which Pollutant May Represent an Environmental Hazard		
Pollutant	Regulated*	Coal Pile Drainage	Ash Pond Effluent	Wastewater
Aluminum	+	++	+	+
Barium	+	±	±	±
Bismuth	+			+
Cadmium	+	+	±	
Calcium	+	+		+
Chlorine	+	++	+	+
Chromium	+	+	±	±
Copper	+	+	±	±
Cresols	+			+
Iron	+	++	−	+
Mangesium	+	+	+	+
Manganese	+	++	−	−
Mercury	+	±	±	±
Naphthalene	−	−	−	+
Naphthols	−			±
Nickel	+	+	±	−
Phenols	+			+
C_3-Phenols	+			+
Phosphorous	−	±		
Selenium	+	+	+	−
Silicon	−	?		
Sulfur	−	+	?	
Xylenols	+			+
Zinc	+	+	±	
pH	+	?	±	

*For this column only, + = yes; − = no.

TABLE 122. POLLUTANTS WHICH ARE LIKELY TO BE HAZARDOUS IN THE INDIVIDUAL SOLID WASTE STREAMS

Pollutant	SRC Mineral Residue	API Separator Bottoms	Biosludge	Fly Ash	Bottom Ash	Flare K.O. Drum	Gasifier Slag
Aluminum	±		±				
Arsenic	+	−		+	±	−	±
Barium	±		−	+	±	−	
Beryllium	±	−		±	−		
Boron	+	±		+			
Cadmium	±	−		+	?		
Calcium	+		±	+			±
Chromium	+	+		+	+	±	±
Cobalt	−			±	±		±
Copper	±	+	±	±	±		±
Fluorine				−	+		
Iron	+	+		+		+	+
Lead	+	+		+	+		±
Lithium				+			
Manganese	+		±	+	+		+
Molybdenum	?*			?	?		
Naphthalene	±						
Nickel	+	±		+	+	±	+
Phosphorus				±			
Potassium	+			+			±
Selenium	+	+		+	−	−	−
Silicon				+			±
Vanadium	−			+	?		
Zinc	+			±	?		±

*? = uncertain.

standards regulating the compositions or constituents in SRC product.

Leaks and spills of SRC product could be regulated to some extent by the proposed rule (40 CFR part 151) establishing requirements for spill prevention control and countermeasure (SPCC) plans. The SPCC plans requirements would be promulgated under the National Pollutant Discharge Elimination System (NPDES) of the Federal Water Pollution Control Act (FWPCA) and would establish measure to prevent discharges of hazardous substances from facilities. The SPCC plan would be prepared in accordance with good engineering practices and the general requirements of providing for appropriate containment, drainage control and/or diversionary structures.

5.7.4.2 Evaluation of Unregulated Toxic Substances and Bioassay Results

A general assessment of the potential hazard of spilled product can be made by comparing product constituents to recommended MATE values. It should be remembered, however, that MATE values are designed as guidelines for effluent concentrations and with regard to the product, would be meaningful only if assessing spill hazard. The same rationale applies to SAM/IA potential degree of hazard assessment which are based on MATE values.

Hittman Associates has utilized Level 1 methodology, and SAM/IA analysis to assess the relative hazard of three product streams of the SRC-II process (naphtha, middle and heavy distillates) and residue. Although the SAM/IA model is intended to be used as a hazard assessment of discharge streams, the model can be a useful indication of the types of compounds which warrant concern in the event of a spill or as a result of fugitive emissions and leaks from product storage.

The level of trace elements found in the naphtha and middle distillates were low in comparison with those in the heavy distillates. None of the trace elements examined, and only aluminum in the naphtha and phosphorous in the middle distillates, exceeded their respective health MATE values. For the heavy distillate many trace elements exceeded the ecological MATE value with some elements such as chromium, manganese and silica exceeding both the health and ecological values.

SAM/IA analysis potential degree of hazard assessment has been performed on the data from Washington State University studies of the trace element distribution and fate in the SRC-I process. A summary is presented in Table 123 of the inorganic elements in three product streams which have degree of hazard numbers exceeding "1" (indicating that the component may be an environmental hazard).

The diversity of organic compounds which can comprise the product streams from the SRC process preclude complete identification without years of research. It has been estimated that only 10 percent of the possible compounds in hydrogenation products have been identified and that those found in the MEGs represent an even smaller percentage. Hittman Associates Level 1 organic analysis of the SRC-II product streams is intended to show relative distribution of broad classes of compounds and to determine, for the middle and heavy distillates, concentration estimates for organics present in highest concentrations.

SRC-I organic constituents as determined by Fruchter and Peterson (63) of Battelle, have been compared with

TABLE 123. INORGANIC ELEMENTS IN SRC-I PRODUCT STREAMS HAVING SAM/IA ANALYSIS POTENTIAL DEGREE OF HAZARDS GREATER THAN "1"

	Potential Degree of Hazard					
	Light Oil-Naphtha		Wash Solvent		Heavy Oil	
Element	Health Based	Ecological Based	Health Based	Ecological Based	Health Based	Ecological Based
Aluminum		6.0				
Antimony		1.2				
Arsenic						4.4
Calcium		11			4.6	69
Chromium					24	24
Copper						20
Iron	6.7	40	2.5	5.6	307	1840
Lead	5.6	28			4.8	24
Magnesium				2.6		
Manganese		1.7			4.4	11
Mercury			3.7	18		
Nickel		15	1.4	32	18	410
Potassium	1.2	1.5			4.3	5.7
Selenium	3.0	6.0			6.9	14
Titanium		6.3		4.7		110
Vanadium		2.4			4.4	73
Zinc		35				88

*The SAM/IA analysis was performed primarily on data of Filby and coworkers of Washington State University (45).

available MATE values. Where such MATEs are available, the product constituents are generally present at concentrations that greatly exceed the MATE, particularly when utilizing the MATE based on ecological effects.

As stated in Section 3.0, a program for the toxicological evaluation of various materials associated with the Solvent Refined Coal process have been divised and is underway at the Fort Lewis pilot plant. Since the toxicological program is still in the early stages and no formal reports have been issued on the results, the following data sources were utilized to assess the potential health and ecological impact from SRC product exposure:

- Bioassay studies of other coal liquefaction oils
- Studies of the effects and hazards of similar fossil fuel substances (e.g., coal, tar, and petroleum)
- Epidemiological studies of similar industries.

Carcinogenic studies of other liquefaction product oils have indicated that carcinogenicity is associated with the oils, excepting the lower boiling point fractions of the light oil. The streams boiling at higher temperature, the middle oil, light-oil stream residue, pasting oil and pitch products were all highly carcinogenic. The degree of carcinogenicity increased and the length of the median latent periods decreased as boiling points rose. Evidence of the carcinogenic potential of SRC product is the presence of known carcinogens (e.g., benzo(a)pyrene) in the product oil.

In summary, the toxicity and carcinogenic potential of SRC products is recognized but difficult to assess because of the incomplete status of SRC studies in these areas.

The environmental hazard of a spill of SRC product would at least equal, and in all likelihood, exceed that created by a spill of similar petroleum oil. The SRC product is suggested to be more carcinogenic than petroleum oils, although this has not yet been verified by laboratory studies. The hazard of skin contact should be greatly emphasized during clean-up of any spill as well as during SRC production and transporting.

The environmental effects of toxic organics in coal liquefaction products and high-boiling, carbon containing residues represent the area of greatest estimated concern. Quantitative definition of the presence and effects of these materials on workplace personnel, other impacted personnel, and the ambient environment is essential.

5.7.4.3 Product Utilization Impacts

A major consideration with regard to SRC product hazard is the impact from utilizing SRC fuels. Emission data from SRC-I and SRC-II combustion tests indicate that the solvent refining process can produce a fuel that when burned gives off lower emissions levels of regulated pollutants than does combustion of the original coal.

SRC-II combustion emission data indicates that NO_x emissions were 70 percent higher than for the petroleum burned in the boiler as a comparison. The SRC-II NO_x level was within the proposed standard of 217 ng/J for coal derived liquid fuels, although the level at times exceeded the present 130 ng/J NSPS for liquid fossil fuel. Other emissions were low. Particulate emissions measured at 0.015-0.025 ppm and are lower than for the oil. Unburned hydrocarbons measured at less than 3 ppm; carbon monoxide was less than 50 ppm; sulfur trioxide less than 1 ppm. No SO_x data were available at the time of this writing.

In comparing the federal emission standards to the SRC-I air emissions test data, SO_2 and NO_x emissions were 460 and 190 nanograms/J, respectively; about 12 and 39 percent under the respective existing New Source Performance Standards (NSPS) of 520 and 300 nanograms/J. If, however, the SO_2 standard is reduced (as proposed) to 260 nanograms/J, SRC derived from high sulfur coal may not meet this standard.

Particulate emissions were less than those from comparable coal combustion and can be controlled well below the EPA standard of 43 nanograms/J by installing a modern precipitator having a particulate collection efficiency of approximately 95 percent. The process of solvent refining of coal results in the removal of some high volatile trace elements, such that, when SRC is burned, lower concentrations of these elements appear in the combustion gases. When comparing trace element levels with the MATE values, only chromium exceeded the recommended level (16 $\mu g/m^3$ versus the MATE of 1 $\mu g/m^3$).

The release of organic constituents to the air, via combustion of SRC, does not appear to be an area of major environmental concern. The emissions of C_1-C_{12} hydrocarbons do not appear to differ significantly from direct combustion of coal and are not an area of environmental concern. Also, no carcinogenic PAHs were found in the SRC flue gases.

The level of volatile trace elements in the combustion emissions are generally less with combustion of SRC than with coal. Comparing the concentrations of 17 inorganic elements in SRC-I combustion emissions with recommended MATE values, only chromium exceeded the recommended level. Analysis was not performed, however, on three elements (titanium, beryllium, and cobalt) which have been reported to be present at levels in SRC product oil which could potentially pose a pollution problem when burned.

5.7.5 Other Impacts

The inability to precisely define the major environmental impacts resulting from the construction and operation of SRC plants, dictated by the fact that no commercial-sized SRC liquefaction plant has yet been built, does not deter one from calling attention to other impacts that may be significant and deemed as adverse and unavoidable. As pointed out by others, generic environmental considerations are useful for program planning and decision making (138).

The most striking impacts resulting from the 20-year lifetime of the proposed synthetic fuels program would result from the commitment of the nonrenewable resources, coal, construction materials, and the land area; these impacts would be essentially irreversible. Once these resources are commited, an inevitable sequence of events would be set in motion effectively cutting across the economic, sociocultural, political, regulatory, land use, and water use aspects of the affected communities.

Estimates of the total commitment of construction materials and coal to the year 2000 are shown for a national synfuels program in Tables 124 and 125. The results in

TABLE 124. TOTAL COMMITMENT OF CONSTRUCTION MATERIALS

Long-Term Production Levels	Steel (1000 Mg)	Copper (1000 Mg)	Aluminum (1000 Mg)
High	22,498	218	699
Intermediate	12,338	118	351
Low	5,107	50	154

*Assumes total production is equally divided among high-Btu gasification, low-Btu gasification, liquefaction and oil shale plants during 1985 to 2000 (138).

TABLE 125. ESTIMATED MAXIMUM ANNUAL COAL CONSUMPTION BY SYNFUELS PLANTS BY THE YEAR 2000 (145)

Production Level in Year 2000	Coal Consumed* (Billion of Mg)	Percent of Recoverable Coal Reserves**
High	2.4	0.9
Intermediate	1.3	0.5
Low	0.5	0.2

* Assumes 100 percent of synfuels production is from coal.

**See reference (138).

Table 124 are reported to indicate that the highest annual steel, copper and aluminum requirements would be less than 1.3, 0.9, and 1.0 percent, respectively, of the 1976 U.S. primary annual production (138). In a similar vein, assuming that 100 percent of the synfuels production would be from coal, as opposed to oil shale, tar sands, or other alternatives, the estimated maximum annual coal consumption (i.e., for the high production level in year 2000) would be about 0.9 percent of the current recoverable coal reserves (Table 125). These data suggest the eventual need to recycle construction materials (steel and copper), and the need to develop alternatives to coal.

With reference to the land area committed to mines and to synfuels plants for the lifetime of the SRC system, the numbers are appreciable and relatively more serious than those for other nonrenewable resources. For example, the estimated land area consigned to the coal-mine area, the landfill at mine and the mine support buildings comprises about 94 percent of the total land area estimated for an SRC complex, assuming that the buffer zone surrounding the SRC plant was 777 hectares (43). The land area estimated for the commercial SRC plant (including cooling ponds, coal storage area, tank farm and coal preparation plant) comprises about 1121 ha, or six percent of the 17,693 hectare area (43). These data suggest that consideration should be given to locating synfuels plants in one county area, and locating surface mines in areas outside that county because the land area required for the additional housing, urbanization, recreation, pipelines, roads and waste disposal would likely come from the county selected for the commercial SRC plant. Land area required annually for the diposal of solids wastes is reported to range from 1619 to 6880 hectares, assuming that the maximum annual production of syncrude would come from coal and operating efficiencies comparable to 1977 (138).

Other major impacts relate to human resources; these include: the changes in socioeconomic; sociocultural; life style; land use; water use; and archeological, historical and esthetic values. As pointed out elsewhere in this report, any generic assessment of these impacts would suffer from the fact that the possible range could be as varied as the elements that characterize the different community profiles. As pointed out by others (141), the severity of community impacts would depend upon the capacity of the local structures to adjust to accelerated demands for public and private goods and services; these structures have been divided into four major categories (141):

(1) Population and labor supply structure

(2) Private industrial supply structure

(3) Political and taxing system structure

(4) Basic community infrastructure

Short-term impacts on human resources in rural, remote areas are expected to be greatest during the construction phase because of the potential influx of thousands of skilled workers and associated elements. Descriptions of these community characteristics, coupled with those for the SRC facility, can provide the baseline information needed for impact assessment. Generic impacts that might result from the construction and operation of a unit synthetic fuels plant are presented elsewhere (138). Suffice to say that the influx of construction and mining workers would be more pronounced in the less densely populated areas of EPA Regions VIII and IX (the Powder River, Fort Union and Four Corners coal areas). For example, provision of necessary health services requirements alone could severely strain local governments of these areas in raising the needed revenues. These and other potential stresses emphasize the need for advanced planning to prepare for future growth.

Water use impacts would be most severe in the arid and semiarid western states (i.e., EPA Regions VI, VIII and IX). For example, any loss of agricultural water rights through transfer to industrial or municipal users could lead to serious inroads or irrigated farmlands.

Major unavoidable impacts to esthetic and human interest values would encompass the hyperurbanization of rural areas, the overloading of federal and state parks and recreational areas, and the disturbances of archeological, historic, and natural preservation areas (138).

5.8 Siting Considerations

In the present state-of-the-art for selecting and screening sites for SRC plants, the acceptability of such sites presumably would be based on information that allows the determination of a suitable balance of benefits, risks and costs, both environmental and socioeconomic. This information would then be embodied in the environmental impact assessment (EIA) report or the environmental impact statement (EIS) submitted by those in the federal sector who propose to construct and operate pilot or demonstration synfuels plants, as required under the final regulations on EIS's issued by the CEQ in 1978, with an effective date of July 31, 1979 (FR-78).

Three additional basic requirements that must be met for the proper siting of commercial synfuels plants are as follows:

- Sufficient reserves of mineable coal of the proper rank and other characteristics to meet the 20-25 year operating needs of the plant.

- Sufficient volumes of surface and/or groundwaters, on a day-to-day basis, to meet the 20-25 year lifetime water needs, and

- Compliance with systems of federal, state, and local standards for air, water and land quality and worker health protection in all areas.

Certain of the synfuels EIA's and EIS's reportedly will be prepared during the design phase, while others appear scheduled for much later stages of a project when site alternatives and design modifications could be given more serious consideration (132,142). Although this approach appears consistent with a slowly evolving synfuels technology, its wisdom can be questioned on the basis of the following assumptions:

- The substantive land use and growth control features of the Clean Air (PSD requirements), Clean Water, and Toxic Substances Acts change rapidly with time, thereby requiring site screening and selection decisions far in advance of the preparation of the EIA's and EIS's for pilot and demonstration plants. This need is magnified by the fact that some of the projected commercial synfuels plants will probably be built and operated at the mine mouth in rural or remote areas where advanced planning is mandatory.

- The current approach to impact assessment appears to place greater emphasis on the use of technologically feasible pollutant control techniques, than on the initial screening and selection of sites which, by definition, could require the use of less sophisticated and less expensive controls; this latter approach could automatically result in the early identification of sites more suitable for synfuels development.

- Estimation of environmental benefits versus the costs or impacts of an SRC technology are best made on a site specific basis at the level of a county, rather than on a statewide or regional basis.

- Procedures for the screening and selection of commercial SRC sites need be no more rigorous than those currently being used for the siting of fossil or nuclear power plants.

- The current programs to evaluate the environmental health and safety issues unique to the Solvent Refined Coal liquefaction technology, suffer from the lack of a well-coordinated effort that would, under realistic operating conditions, permit the selection of precise equipment design and operating conditions concurrently with the assessment of health and ecologic risks; these studies should be conducted at pre-selected sites judged suitable for the construction and operation of commercial-sized SRC facilities.

The major thrust of these assumptions is to emphasize the need and the importance of screening and selecting potential sites (or candidate sites) for the construction and operation of demonstration and near-commercial sized SRC plants at a much earlier date than presently envisaged. This approach dictates the use of a process of successive evaluations, extending from the generic to the site specific and culminating in more realistic overall impact assessments. Present knowledge clearly indicates that the SRC technology possesses unique environmental problem areas over and above those common to other fossil energy systems; these problem areas will require the application of considerations of both a design and site selection nature. Finally, this emphasis is consistent with the perceived limitations of federal programs, under NPDES, that require an industry to report on the hazardous substances that will be discharged and to assess their environmental impacts (143).

5.8.1 Major Stages and Steps of the SRC Siting Methodology

The basic considerations and exclusions involved in choosing acceptable sites are diverse and complex, in that these factors may be applied in both the generic and site specific contexts. Figure 71 represents a generalized power plant siting methodology judged applicable to the synfuels technology, based on a survey of siting methods in current use by U.S. utilities (138).

Suggested steps for the three different stages in the siting of potential SRC plants reflect the premise that the use of a series of successive evaluations, extending from the generic to the site specific, will culminate in acceptable and timely overall impact assessments. Each stage of

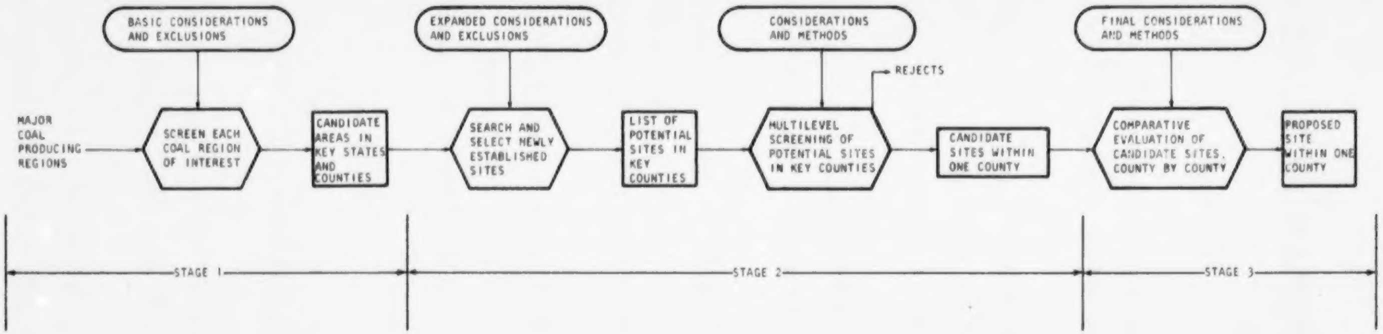

BASIC CONSIDERATIONS AND EXCLUSIONS
EXPANDED CONSIDERATIONS AND EXCLUSIONS
CONSIDERATIONS AND METHODS
FINAL CONSIDERATIONS AND METHODS
REJECTS
MAJOR COAL PRODUCING REGIONS
SCREEN EACH COAL REGION OF INTEREST
CANDIDATE AREAS IN KEY STATES AND COUNTIES
SEARCH AND SELECT NEWLY ESTABLISHED SITES
LIST OF POTENTIAL SITES IN KEY COUNTIES
MULTILEVEL SCREENING OF POTENTIAL SITES IN KEY COUNTIES
CANDIDATE SITES WITHIN ONE COUNTY
COMPARATIVE EVALUATION OF CANDIDATE SITES, COUNTY BY COUNTY
PROPOSED SITE WITHIN ONE COUNTY
STAGE 1
STAGE 2
STAGE 3

Figure 71. Power plant siting methodology.

this approach to the siting process may have three or more steps, as follows:

Stage 1 - Determination of Candidate Areas

Step 1

- Identify major characteristics of the coal region that influence site selection
- Establish and apply basic considerations and exclusions, with emphasis on feasibility of compliance with environmental standards
- Ascertain for each coal region if mine mouth locations are feasible on a county basis
- Integrate preliminary system planning and design relative to environmental/sociocultural concerns as well as basic engineering considerations.
- Establish preliminary coordination with federal, state and local agencies; provide for citizen participation in decision making.

Step 2

- Conduct a straightforward generic evaluation of states in a single region of interest having water and coal supplies sufficient to cover the 20-25 year lifetime of the SRC plant
- Expand basic considerations and exclusions if necessary, and select 3-7 counties in each state comprising one coal region.

- Within the selected counties establish several geographic zones of interest for SRC plant locations (number of zones will vary with size of county, its geomorphology etc., and may range from 2 to 8); maps or aerial reconnaissance may be used depending on the area.

Step 3

- Make successive generic evaluations of coal, water, critical areas, land use, and water use conflicts within the context of total system requirements

- Designate specific candidate areas (1 to 10) in the several zones of interest of key counties; these candidate areas may contain up to a total of 200 candidate sites.

Stage 2 - Determination of Candidate Sites

Step 1

- Develop a list of extended engineering, environmental, health and safety, system planning, institutional, and socioeconomic considerations and exclusions suitable for more refined multilevel screening of candidate sites. Suggested site selection parameters and characteristics for site comparison are listed in Section 5.8.2. Most of the overall data needed at this step can be obtained from public documents.

Step 2

- Use successive screening to eliminate less desirable sites by use of a suitable site comparison matrix; carefully check previous data.

Step 3

- Prepare, through successive, multilevel screening, a list of potential sites in key counties; this list could contain from 10 to 200 sites. Conduct preliminary studies at sites lacking adequate data.

Step 4

- Select from 2 to 12 potential sites from the collective zones of interest in key counties by weighting all controlling site parameters and information collected from preliminary onsite surveys.

Stage 3 - Determination of the Most Acceptable Sites

Step 1

- Elaborate and refine the engineering, environmental, and socioeconomic (human resources) considerations used in Stage 2 for selecting the candidate sites. Strong emphasis is required with reference to the development and end impacts.

Step 2

- Develop a formalized, numerical rating system (e.g. the site evaluation process is more likely to be comparative or relative in nature, hence more site specific) to identify relative environmental impacts at the most acceptable sites. Most emphasis should be placed on identifying the irreversible adverse impacts on all media and resources.

Step 3

- The selection of sites that will be relatively free of potential environmental damage is key to this step, and will depend on how effective the rating/weighting system was in the weeding-out process. If such an end is achieved, the final siting decision will be strongly cost-oriented and various cost comparison analyses may be used (144). However, where significant differences between candidate sites are noted, separate, detailed cost and environmental considerations will be required (144).

Further discussion of the use of the joint site selection and impact assessment methodology is presented in the Appendices.

5.8.2 Basic Siting Considerations

Basic considerations to be addressed in the siting of potential SRC plants have been suggested, as follows (144):

- System planning and design

- Regulatory standards, guidelines and criteria

- Engineering factors at the site(s)

- Abiotic and biotic environmental considerations

- Sociocultural and socioeconomic considerations

- Institutional factors and key issues

Further discussion of each of these basic siting considerations is presented in the Appendices.

5.8.3 Basic Exclusions

Basic exclusions to be addressed in the siting of potential SRC facilities are suggested as follows:

- Lack of an adequate and useable water supply for the 20-25 year life of the facility

- Lack of an adequate supply of coal

- Prohibitive nearness to natural preserves, wilderness, and Indian lands.

- Prohibitive nearness to pristine air and water resources

5.8.4 Suggested EPA Regions for Siting Synfuels Plants

The National Coal Policy Project (NCPP) recently recommended that coal development technologies should be concentrated in EPA Region III (the States of West Virginia and Pennsylvania), EPA Region V (the States of Illinois, southwestern Indiana, EPA Region IV (western Kentucky) and in EPA Region VIII (the States of Montana and Wyoming).

Based on a siting study of the 14-state midwest region, the Argonne National Laboratory Regional Studies program (ANLRS) forecasted, on the basis of an accelerated synfuels scenario, that by the year 2020 the distribution of coal liquefaction plants in the five states exhibiting a suitable coincidence of useable water and coal resources, would be as follows (145):

State	Number of Plants	EPA Region
Illinois	5 plants	V
Indiana	2 plants	V
Missouri	1 plant	VII
North Dakota	6 plants	VIII
Ohio	2 plants	V

Coal producing states having the highest potential for accommodating synfuels plants were reported to be: southwestern Ohio; southwestern Pennsylvania; northeastern West Virginia; Illinois; western Kentucky; western North Dakota; southeastern Montana; northeastern Wyoming; northwestern New Mexico, and northeastern Arizona (138). Additional details on the selection of desirable sites for synfuels plants is given in the Appendix.

6.0 SUMMARY OF NEEDS FOR ADDITIONAL DATA

6.1 Categories of Data Needs

Sections 2 to 5 of this report constitute a one-source reference of available environmental information pertinent to Solvent Refined Coal (SRC) liquefaction systems. In the accumulation and analysis of the information presented, additional data needs have been identified for inclusion in revisions to this environmental assessment report. Presumably, this approach will permit refinements of environmental assessment information to parallel progress in process development so that when commercial SRC facilities emerge, the risk of adverse environmental impacts is minimized.

Existing information needs generally fall into one of two categories: data on waste stream characteristics for use in development and enforcement of realistically attainable discharge standards; and information which facilitates control technology research and development and increases the accuracy of predictive methodologies in estimating SRC systems effects on the environment.

The remainder of subsection 6.1. is a discussion of the data needs identified. Subsection 6.2 overviews near-term efforts to obtain additional environmental data on SRC systems.

6.1.1 Data Needs to Support Standards Development and Enforcement

Development of New Source Performance Standards (NSPS) for SRC systems require compilation and evaluation of applicable environmental data. As a minimum, an environmental data base on SRC systems should include the following information:

- Characterization of SRC waste streams via sampling and analysis
- Effects of system variables on waste stream characteristics
- Performance/cost of applicable control technologies
- Environmental impacts associated with SRC production/utilization.

The first two items are discussed in this subsection. The latter two items, which indirectly influence standards development are discussed in subsection 6.1.2.

To provide accurate characterization of SRC waste streams requires the development and implementation of sampling and analysis methodologies. Current sampling and analysis activities at the Wilsonville and Fort Lewis pilot plants satisfy two objectives necessary for standards development. The first objective is to obtain preliminary waste stream characterization data for an environmental data base. The second objective is to evaluate and improve the sampling and analysis methodologies employed and to establish priorities for subsequent sampling and analysis efforts. Results of waste stream characterization at the pilot level can then be used in development of programs for SRC-I and SRC-II demonstration scale facilities. Sampling and analysis at the demonstration scale will provide results more applicable to commercial facilities than previous pilot-scale work (especially if commercial facilities consist of parallel trains of demonstration-scale equipment as has been suggested. Detailed characterization of waste streams produced during operation of the demonstration plant would vastly expand the existing environmental data base. This data base, augmented by data on control technology options and results of environmental impact assessments, will permit development of improved preliminary standards for the first commercial SRC plants. Expansion of the data base by continuing sampling and analysis of the commercial facilities during their early years of operation would permit revisions of the preliminary standards if necessary.

Another key consideration in developing an environmental data base on SRC production is identification of factors which may significantly affect waste stream characteristics. For instance, New Source Performance Standards (NSPS) based on SRC plants converting feed coal of 2 wt. percent sulfur may not be obtainable by SRC plants converting 4 wt. percent sulfur feed coals. Other factors which may influence waste stream characteristics include feed coal ash content (as well as other aspects of feed coal composition), process operating conditions (in particular operating characteristics of the dissolver), and operating mode (SRC-I vs. SRC-II). Planning efforts for sampling and analysis activities must be directed toward compiling an environmental data base considered most representative of any and all conditions which may exist in commercial SRC plants.

Characterization of SRC waste streams products, and byproducts and determination of those processing variables which influence these streams' characteristics are both essential to estimation and minimization of environmental impacts. For example, compounds containing cyclic nitrogen species are present in SRC product liquids. Such compounds pose a hazard to workers and the environment (due to oil and grease in process wastewater discharges). Process changes in hydrotreater operating conditions or catalyst may permit increased conversion of cyclic nitrogen compounds to recoverable ammonia, thereby lessening the risks of workplace health hazards and adverse environmental impacts.

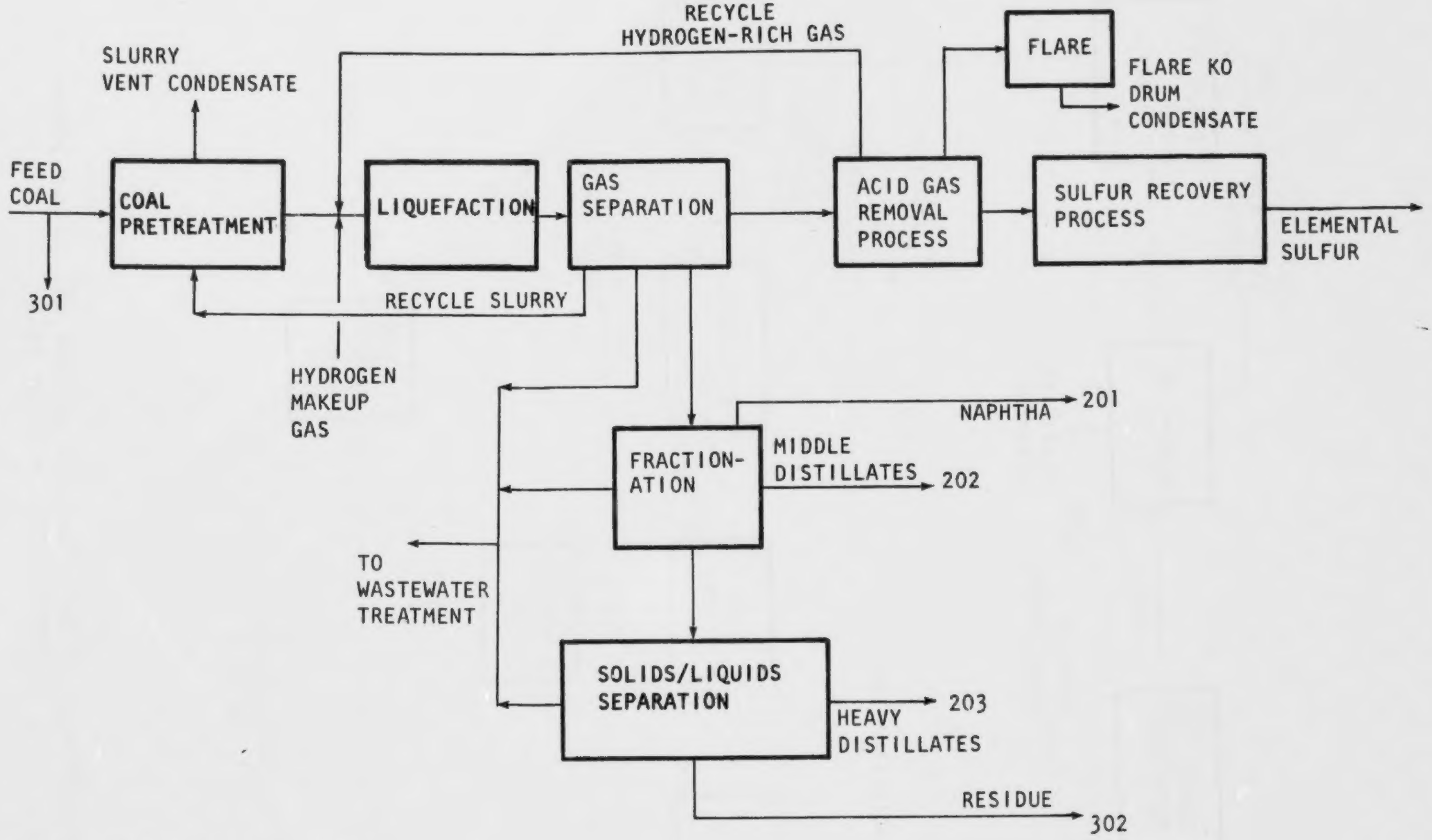
Table 126 summarizes the extent to which SRC waste streams can be characterized in terms of the existing availability of the processes proposed for use in future commercial facilities. From the table it can be seen that not all processes to be included in SRC commercial facilities are being used in current pilot plants, notably hydrogen generation and hydrotreating. Hydrotreating, an optional operation for upgrading product quality is not part of the Fort Lewis or Wilsonville pilot facilities. Makeup hydrogen is provided by conventional technology (e.g., natural gas refining) rather than gasification of SRC mineral residue or filter cake.

A 1978 visit to the Fort Lewis SRC facility (at that time operating in the SRC-II mode) was made by Hittman Associates, personnel with the objective of obtaining product and grab samples from the plant's wastewater treatment system (41). Figures 72 and 73 show the pilot facility and wastewater treatment scheme respectively. Samples obtained are indicated in the figures.

The Fort Lewis pilot plant facility is not, by design, a minature version of a commercial SRC facility. Any conclusions concerning the applicability of pilot plant data to a commercial-scale plant must include consideration of the pilot plant design as well as its scale, the applicability of the streams and samples to a larger plant, and its operation.

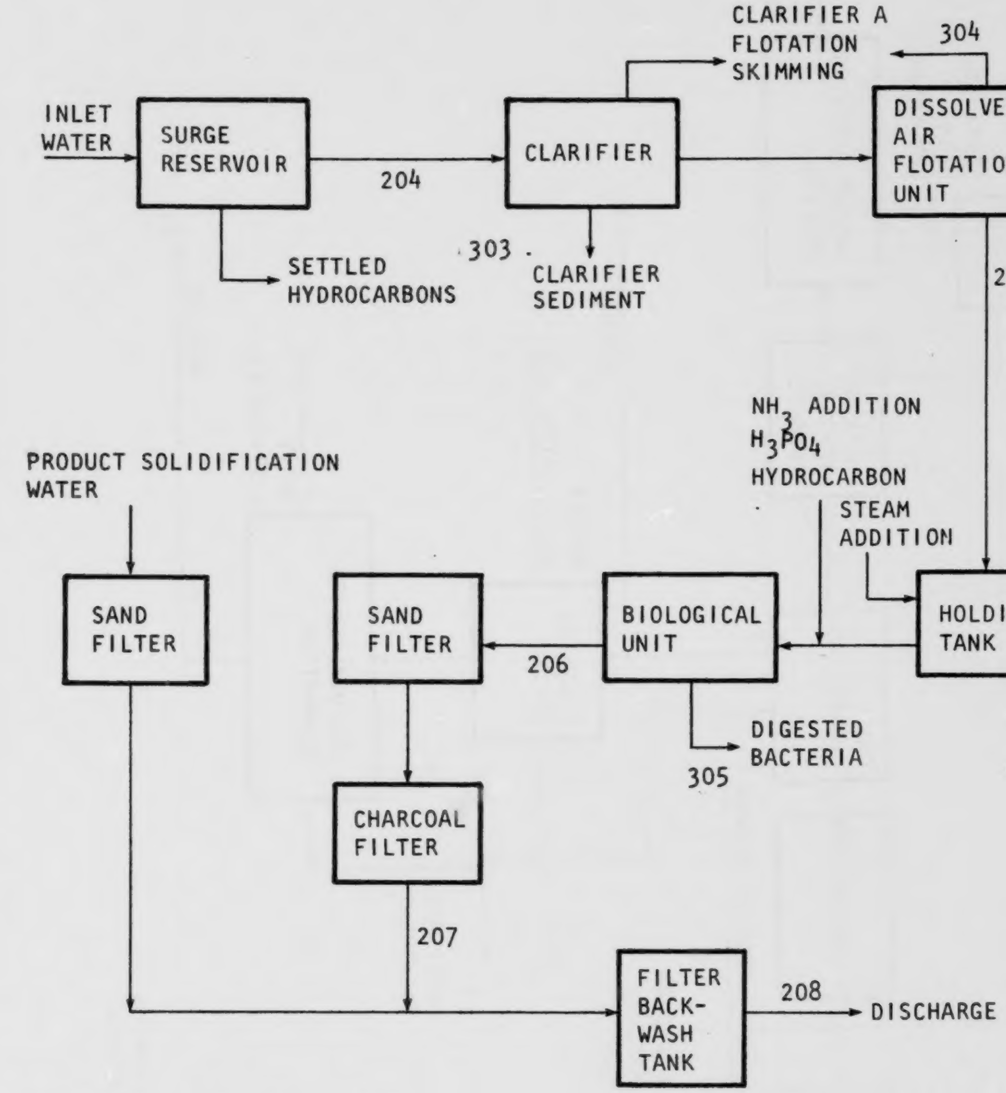
TABLE 126. TECHNICAL AVAILABILITY OF COMMERCIAL SRC SYSTEM COMPONENTS

Operation/Auxiliary Process	Part of SRC Pilot Facilities	Commercially Available/Applications
Coal preparation	Yes	Yes/coal and power production
Liquefaction	Yes	No
Gas separation	Yes	No
Fractionation	Yes	Yes/petroleum industry
Solid/liquids separation	Yes	No
Hydrotreating	No (not essential-upgrades products)	Yes/petroleum industry
Coal receiving & storage	Yes	Yes/coal and power production
Water supply	Yes	Yes
Water cooling	Yes	Yes
Steam & power generation	No (not produced on-site)	Yes
Hydrogen generation	No (industrial hydrogen used)	No
Oxygen generation	No (not required)	Yes/industrial gas manufacturing
Acid gas removal	Yes	Yes/petrolum industry
Sulfur recovery	Yes	Yes/petroleum industry
Hydrogen/hydrocarbon recovery	Yes	Yes/petroleum industry
Ammonia recovery	No	Yes/chemical industry
Phenol recovery	No	Yes/chemical industry
Product/by-product storage	Yes	Yes/petroleum industry


RECYCLE HYDROGEN-RICH GAS
SLURRY VENT CONDENSATE
FLARE
FLARE KO DRUM CONDENSATE
FEED COAL
COAL PRETREATMENT
LIQUEFACTION
GAS SEPARATION
ACID GAS REMOVAL PROCESS
SULFUR RECOVERY PROCESS
ELEMENTAL SULFUR
301
RECYCLE SLURRY
HYDROGEN MAKEUP GAS
NAPHTHA
201
FRACTION-ATION
MIDDLE DISTILLATES
202
TO WASTEWATER TREATMENT
SOLIDS/LIQUIDS SEPARATION
203
HEAVY DISTILLATES
RESIDUE
302

NOTE: 200s = liquid samples
300s = solid samples

Figure 72. Overall flow schematic for the SRC-II pilot plant (41).



INLET WATER
SURGE RESERVOIR
204
CLARIFIER
CLARIFIER A FLOTATION SKIMMING
304
DISSOLVED AIR FLOTATION UNIT
SETTLED HYDROCARBONS
303
CLARIFIER SEDIMENT
205
NH_3 ADDITION
H_3PO_4
HYDROCARBON
STEAM ADDITION
PRODUCT SOLIDIFICATION WATER
SAND FILTER
SAND FILTER
206
BIOLOGICAL UNIT
HOLDING TANK
DIGESTED BACTERIA
305
CHARCOAL FILTER
207
FILTER BACK-WASH TANK
208
DISCHARGE

NOTE: 200s = liquid samples
300s = solid samples

Figure 73. Overall flow schematic of the SRC pilot plant wastewater system (41).

As can be concluded from Section 3.0 of this report, existing information on waste characterization of SRC systems is limited to conceptual designs, based on minimal pilot data. This fact, in conjunction with conclusions from the HAI visit to Fort Lewis, tend to indicate the following regarding future sampling activities:

- Data obtained by sampling of pilot facilities should be regarded as preliminary data, useful primarily for establishing priorities for future sampling efforts at the demonstration and commercial levels.
- That sampling efforts at the pilot facilities be used to gain expertise in applying sampling and analysis methodology.
- Future sampling efforts can identify problem areas which can result in additional refinement of the existing methodology and procedures.

6.1.2 Data Needs To Support Effects and Control Technology Research and Development

Control technology performance and estimates of environmental effects are interrelated subjects. Optimum environmental assessment of SRC systems will require additional data in these areas. These data will also be supportive in development of standards as discussed in Section 6.1.1.

Efforts to secure additional data for effects and control technology research and development should be directed to the following areas:

- Additional waste stream characterization by sampling and analysis activities (discussed in Section 6.1.1.)

- Ambient and background monitoring studies

- Regional and/or site-specific studies

- Testing of applicable control technologies.

Data needs relevant to monitoring, regional/site-specific studies, and control technology testing are overviewed in the remainder of this subsection.

Ambient monitoring of air and water quality in the vicinity of existing SRC pilot facilities should be performed to determine if any changes occur that are attributable to operation of the facility. Preconstruction background monitoring at the site of proposed future facilities, followed by ambient air and water quality monitoring during the construction, startup and operation of the facility are essential components of an environmental effects data base. Prerequisite to this effort is the need to define and determine the availability of sites of future SRC facilities. Proposed sites for SRC demonstration facilities should be given first priority with additional attention directed to other acceptable sites for commercial plants. Monitoring and stream characterization data can be used to evaluate and improve environmental impacts and effects methodologies. In this manner, estimates of environmental effects can be improved consistent with technical development and SRC waste stream characterization efforts.

Prediction of environmental impacts requires regional and site-specific information as well as data on ambient air and water quality. Among the types of information required are:

- Climatic factors such as precipitation frequency and direction of prevailing winds
- Geologic factors such as groundwater availability and quality and suitability of locations for solid waste disposal
- Biological and ecological factors, including the types of plant and animal life indigenous to the area
- Sociological factors - for example, the proximity of residential, commercial or industrial facilities to proposed SRC plant sites.

It is of particular value to compile such information prior to and during construction of the SRC-I and SRC-II demonstration plants. Application of waste stream characterization, background monitoring and regional/site-specific data can permit preparation of preliminary environmental assessments prior to construction of future proposed SRC facilities.

To date, assessments of control technology applicability in SRC systems have been based primarily on engineering evaluations of candidate control technology costs and estimates of performance when matched with SRC waste stream characteristics. Such assessments, while valuable in determining applicable control technologies, may require supplemental site-specific testing of candidate control technologies to establish which control technologies are best for that particular facility. Data collected during such tests would be useful in standards development and enforcement, evaluation of environmental effects/impacts, and in minimizing SRC production costs.

Small-scale testing of control technology alternatives is a cost-effective method which provides valuable data for evaluation of full-scale control technology performance. Candidate control options, such as the zero aqueous discharge scheme described in Section 4.7 can be skid mounted on a flatbed truck and tested at SRC pilot or demonstration facilities. Bleed streams of untreated wastewater from the plant would be directed to the small-scale unit for treatment. Samples of treated water could then be analyzed for evaluation of control technology performance and environmental effects.

Again, it should be reemphasized that the existing SRC pilot facilities are not entirely representative of commercial or even demonstration facilities, particularly in terms of waste stream characteristics. Assessments of environmental impacts or control technology applicability must be viewed as preliminary, in the absence of actual commercial-scale, site-specific data. The major value of such assessments is to obtain preliminary data, evaluate assessment techniques and gain expertise for performing subsequent efforts.

6.2 Data Acquisition by Ongoing Environmental Assessment Activities

6.2.1 Ongoing IERL-RTP Environmental Assessment Activities

As a contractor of EPA Industrial Environmental Research Laboratory-Research Triangle Park (IERL-RTP), Hittman Associates is continuing work efforts on a program to perform a multimedia environmental assessment of coal conversion to liquid fuels energy technologies, including utilization of the product fuels in stationary souce applications. One project key to the environmental assessment of SRC systems was performed in February, 1979: sampling of the SRC pilot plant at Fort Lewis, Washington. Primarily, samples of emissions to air and wastewaters before treatment were taken. Both EPA Level 1 and Level 2 sampling procedures will be employed in this effort. Subsequent to sampling, analysis of air emissions and wastewater samples will be performed at Hittman's analytical laboratory.

As part of this effort, several subcontractors are providing technical support for both on-site sampling and analysis activities. Analyses to test both chemical and biological characteristics of SRC samples are included in the program.

6.2.2 Other Ongoing Environmental Assessment Activities

The United States Department of Energy (DOE) is the government agency sponsoring other SRC environmental assessment activities. A list of DOE contractors and subcontractors presently involved in SRC environmental assessment is shown in Table 127. Research objectives and technical approaches taken are included in the table.

TABLE 127. DOE CONTRACTORS AND SUBCONTRACTORS

Contractors and Subcontractors	Area of Research	Reference of Available Reports	Data Source	Technical Approach
Pittsburg and Midway	Future demonstration plant - engineering design		Future plant	Design and preparation stage of 6000 T/D SRC-II plant, to be built near Charlestown, W. Virginia
	Ft. Lewis pilot plant - overall operation:	(48)	Fort Lewis	Monitoring in pilot plant for potential air and skin contaminants
	- Health Programs: Industrial hygiene program			Monitoring in pilot plant for potential air and skin contaminants
	Clinical examination program			Periodic visual skin examinations and pulmonary function tests
	Educational program			Health protection indoctrination presentations
	Toxicological program			Animal bioassays. Program not now operating - see below "New subcontractor to be awarded in future"
Washington State University*	Chemical program - analysis of trace element distribution in SRC-I	(49)	Fort Lewis	Neutron activation analyses (NAA) and atomic absorption spectroscopy (AAS) are utilized
Alsid, Snowden & Associates*	Environmental sampling/monitoring program	(50)	Fort Lewis	Ongoing air, water and foliage monitoring (sampling & analysis) studies of environment surrounding SRC pilot plant
New subcontractor to be awarded in near future*	Toxicology program		Fort Lewis	Based on animal bioassays of various product and intermediate streams from the SRC process, using short and long-term (2 year) studies
Battelle Northwest Laboratories	Biomedical program - Mutagenicity of SRC materials - Toxicity of SRC materials - Late effects (carcinogenicity) of SRC materials	**	Fort Lewis	
	Ecological program - Acute and chronic toxicological studies	**	Fort Lewis	
	Chemical program - Sampling and analysis to characterize products, by-products and effluents from SRC process	**	Fort Lewis	Development of appropriate sampling techniques. Inorganic analysis by utilizing NAA, X-ray florescence (XRF), and chemical speciation methods. During organic analysis, extracts are partitioned into acidic, basic, polynuclear aromatic and neutral fractions which are analyzed by gas chromatography/mass spectrometry (GC/MS) and high pressure liquid chromatography

(continued)

TABLE 127. (continued)

Contractors and Subcontractors	Area of Research	Reference of Available Reports	Data Source	Technical Approach
Illinois State Geological **Survey**	Chemical program - to determine the recoverable and/or economic amounts of valuable or semi-valuable metals in solid residues from SRC and other liquefaction processes	(146)		Analytical determinations of over 60 elements in feed coal and the liquefaction residues of several separate processes under multiple conditions
Consolidated Edison of NY and the Electric Power Research Institute	Burn test of SRC-II fuel to determine if it would meet EPA emission standards	***	Fort Lewis	4500 barrels of SRC-II fuel were burned, followed by a comparison burn test using low-sulfur oil

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* Subcontractors to Pittsburg and Midway

** Annual reports should be out in **early summer**, 1979. A draft "Program Planning Document" is nearing completion. The purpose of this document is to describe the research program which will provide a data base integrated environmental assessment of SRC technology.

***Work still being conducted on the test burn. A final report is therefore not yet available **as of this writing.**

DOE's primary SRC contractor is the Pittsburg and Midway Coal Mining Company (P&M), a subsidiary of Gulf Oil Corporation. P&M is responsible for overall operations at the SRC pilot plant facility in Fort Lewis, Washington. Extension of current P&M-DOE contracts, including subcontracts, effective January 1, 1979, has permitted continuation of environmental assessment activities. Discussions of these programs, including progress to date, is provided in Subsection 3.1.2. As mentioned in Section 2.0, P&M is also involved in the design of an SRC-II demonstration facility.

Stearns-Roger Corporation is currently engaged in a study to provide baseline monitoring data for the proposed facility site (147).

Battelle Northwest Laboratories (51) is engaged in three major programs for assessment of materials from SRC systems:

- Biomedical program - testing for toxicity, carcinogenicity and mutagenicity.
- Ecological program - acute/chronic toxicological studies
- Chemical program - sampling and analysis to characterize streams of SRC systems.

Intensive SRC environmental assessment research activities at Battelle Northwest Laboratories have been underway for approximately one year. Currently, minimal information is available on this effort, however, it is anticipated that an annual report will be prepared by early summer, 1979. Battelle Northwest Laboratories is also preparing a "program planning document", the purpose of which is to outline a research program to provide a data base for integrated environmental assessment of SRC systems (51).

Under contract with DOE the Illinois State Geological Survey is engaged in a study to determine if the solid residues produced by SRC and other coal liquefaction systems contain economically recoverable amounts of valuable or semivaluable metals that could justify classification of the residues as a potential reserve source of such metals. Chemical analysis and macro-mineralogical characterization of SRC residues and parent coal will be conducted. The characterization data obtained in this study may be useful in SRC process optimization studies. Completion of laboratory analyses is scheduled for the end of 1978. A report on the study with analytical findings is scheduled for preliminary review in the spring of 1979 (146).

Consolidated Edison of New York and the Electric Power Research Institute recently participated with DOE in conducting a burn test of SRC-II liquid fuel. The purpose of the test was to demonstrate the utility of SRC-II fuel as a satisfactory substitute for low-sulfur oil and to determine if emissions from combustion would meet the EPA proposed emission standards. A final report is not yet available, but preliminary results appear to be "very encouraging" with regard to the combustion and emission qualities of SRC-II. However, the SRC-II oil produced by the Fort Lewis pilot plant is considerably different than the oil that would be produced by a commercial plant. Interpretation of the test results should be made with full awareness of those differences.

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APPENDICES

APPENDIX A - Glossary

Auxiliary Process: Processes associated with a technology which are used for purposes that are in some way incidental to the main functions involved in transformation of raw materials into end products. Auxiliary processes are used for recovery of by-products from waste streams, to furnish necessary utilities, and to furnish feed materials such as oxygen which may or may not be required depending on the form of the end product which is desired; e.g., the auxiliary processes for low-and medium-Btu gasification technology include: (1) oxygen plant which is used only for medium-Btu gas; (2) the Stretford plant used to recover sulfur compounds from gaseous waste streams.

By-Product Streams: Discharge streams from which useful materials are recovered to: (1) eliminate undesirable environmental discharges; or (2) recover valuable materials which are most economically isolated from process input stream after it has been physically or chemically transformed; e.g., sulfur is recovered as a by-product from coal gasification to prevent pollution while vanadium is recovered from the ash generated by the burning of residual oil to produce electricity because it is profitable to do so.

Closed Process: For the purposes of this report, a closed process signifies a process which has no waste streams.

Coefficient of Runoff: An empirical constant developed for the purpose of predicting the amount of stormwater runoff as a function of average rainfall intensity and drainage areas. The mathematical relationship is as follows:

$Q = CIA$

where: Q = maximum rate of runoff, cubic feet per second (cubic meters per second).

C = coefficient of runoff based on type and character of surface

I = average rainfall intensity, inches per hour (centimeters per hour)

A = drainage area, acres (square meters).

Control Equipment: Equipment whose primary function is to reduce the offensiveness of waste streams discharged to the environment. It is not essential to the economic viability of the process, e.g. if the recovery of sulfur from gas cleaning operations associated with coal gasification involves the use of a Stretford plant. The Stretford process is an auxiliary process and is not control equipment. An incinerator used to clean the tail gas from the Stretford unit would be considered control equipment.

Discharge: The release of pollutants to the environment in the most general sense. Usually applied to intermittent or accidental releases.

Effluent Streams: Continuous aqueous process waste streams which are potentially polluting; these will be discharged from a source.

Emission Streams: Confined gaseous process waste streams which are potentially polluting, these will be discharged from a source.

Energy Technology: A technology is made up of systems which are applicable to the production of fuel or electricity from fossil fuels, radioactive materials, or natural energy sources (geothermal or solar). A technology may be applicable to extraction of fuel, for example, underground gasification; or processing of fuel, for example, coal liquefaction, light water reactor, or conventional boilers with flue gas desulfurization.

Final Disposal Process: Processes whose function is to ultimately dispose of solid or liquid waste containing materials which have potential for environmental contamination. The waste materials treated emanate from the collection of process waste streams for final disposal or from treatment of waste streams using control equipment to collect and concentrate the potential pollutants which are subsequently sent to final disposal. Examples of final disposal processes are landfills and lined ponds.

Flottazur: Dissolved air flotation unit.

Fugitive Emissions: Those emissions of air pollutants not directed through ducts or stacks and not amenable to measurement by established source sampling methods.

Input Streams: Materials which are supplied to a process in performance of its intended function. Input materials will consist of primary raw materials, secondary raw materials, or intermediate products.

Intermediate Products: Process output streams that feed from one process to another within a technology for further processing with another technology; for example, for the low-and medium-Btu gasification technology, gasification converts pretreated coal into raw gas which is an intermediate product input to gas cleaning. Where an intermediate product is further processed using a different technology it becomes a secondary raw material which is described below.

LD50 (Lethal dose, 50%): That quantity of a substance administered either orally or by skin contact necessary to kill 50% of exposed animals in laboratory tests within a specified time.

MEG (Multimedia Environmental Goals): Levels of significant contaminants or degradents (in ambient air, water or land) that are judged to be (1) appropriate for preventing certain negative effects in the surrounding populations or ecosystems, or (2) representative of control limits achievable through technology.

MATE (Minimum Acute Toxicity Effluent): A subset of MEG listing concentration levels of contaminants in air, water, or solid waste effluents that will not produce significant harmful responses in exposed humans or the ecology, provided the exposure is of limited duration (less than eight hours per day).

Opacity Rating: A measurement of the opacity of emissions, defined as the apparent obscuration of smoke of a given rating on the Ringelmann chart.

Operation: A specific function, associated with a technology in which a set of processes are employed to produce similar products starting from the same input material; e.g., some operations associated with the technology for coal liquefaction are: (1) coal preparation where the processes employed are receiving, crushing and sizing, drying, and slurry mixing. These processes will be used in different combinations dictated by the type of coal processed; (2) hydrogenation which can be accomplished using any of six hydrogenation processes; and (3) gas purification, where different processes are employed for pressurized vs. atmospheric systems, cleanup of gases containing tar vs. cleanup of tar-free gas.

Output Streams: Confined discharges from a process which are either end products, intermediate products, by-product streams, or waste streams.

Plant: An existing system (set of processes) that is used to produce a specific product of the technology from specific raw materials. A plant may employ different combinations of processes but will be comprised of some combinations of processes which make up the technology. For example, the Glen-Gery Brick Company low-Btu gasification facilities are plants used to produce combustion gas from anthracite coal.

Primary Raw Materials: Materials which are extracted (such as coal and ores) or grown and harvested (trees, corn, etc.) and processed to yield intermediate or end products. For energy technologies the principal raw materials are fossil fuels, ores for nuclear fuels, geothermal deposits, and sunlight.

Processes: Processes are basic units which make up an operation. A process is employed to produce chemical or physical transformations of input materials into end products, intermediate products, or by-products. Every process has a definable set of waste streams which are, for practical purposes, unique. The term used without modifiers is used to describe generic processes. Where the term is modified, such as, for example, in the term "Lurgi process", reference is made to a specific process which falls in some generic class consisting of a set of similar processes; for example, the low-and medium-Btu gas technology includes the fixed-bed, atmospheric, dry ash gasifier as one of the gasification processes. Specific processes which are included in this generic class are Wellman-Galusha, Woodhall-Duckham/Gas Integrale, Chapman (Wilputte), Riley-Morgan, and Foster-Wheeler Stoic.

Raw Materials: Raw materials are feed materials for processes. They are of two types: (1) primary raw materials that are used in the chemical form in which they were taken from the land, water, or air, and (2) secondary raw materials that are produced by other industries or technologies. For example, primary raw materials for low/medium-Btu gasification technology include coal, air, and water. Secondary raw materials include fluxes, makeup solvent, catalysts, etc.

Residuals: Uncollected discharges from control equipment used to treat waste streams or discharges from final disposal processes which are used for ultimate disposal of waste material; for example, traces of pollutants that pass through a scrubber cleaning the tail gas from the Claus plant used in coal gasification are residuals. If a scrubber is used to clean the Stretford unit tail gas and a bleed stream is sent to a lined pond serving as a final disposal process, any runoff to the environment would be a residual.

Ringelmann Chart: A chart used in air pollution evaluation for assigning an arbitrary number, referred to as the smoke density, to smoke emanating from any source.

Secondary Raw Materials: Materials which are output from one technology and input for another. For the technology with which it is produced, it is an intermediate product. For the technology associated with further processing, it is a secondary raw material; for example, liquid fuel from coal is an intermediate product from coal liquefaction and, if it is burned utilizing a technology associated with production of electricity, it is a secondary raw material.

Six-tenths Factor: A logarithmic relationship between equipment size and cost, used to adjust one set of estimates to a different design size. The simple form of the six-tenths factor is:

$$C_n = r^{0.6}C$$

where C_n is the new cost, C is the previous cost, and r is the ratio of new to previous capacity.

SAM (Source Analysis Models): A methodology which allows the quick identification of possible problem areas where a suspected pollutant exceeds the MEG.

SRC System: A noncatalytic direct-hydrogenation coal liquefaction process for converting high-sulfur and ash coal into clean burning gaseous, liquid or solid fuels.

SRC-I Product: A solid coal like product of less than one (1) percent sulfur and 0.2 percent ash.

SRC-II Product: A low-sulfur fuel oil of 0.2 to 0.5 percent sulfur, and naphtha product.

Threshold Limit Value (TLV): A set of standards established by the American Conference of Governmental Industrial Hygienists for concentrations of airborne substances in workroom air. They are time-weighted averages based on conditions which it is believed that workers may be exposed to day after day without adverse effects. The TLV values are intended to serve as guides in control of health hazards, rather than definitive marks between safe and dangerous concentrations.

System: A specified set of processes that can be used to produce a specific end-product of the technology e.g., low- and medium-Btu gasification. The technology is comprised of several systems. The simplest system is producing combustion gas from coal using a small fixed-bed, atmospheric, dry ash gasifier coupled with a cyclone. One of the most complex systems has very large gasifiers with high efficiency gas cleaning being used to produce a fuel clean enough to be fired in the gas turbines of a combined-cycle unit for production of electricity.

Waste Streams: Waste streams are confined gaseous, liquid, and solid process output streams that are sent to auxiliary processes for recovery by-products, pollution control equipment or final disposal processes. Unconfined "fugitive" discharges of gaseous or aqueous waste and accidental process discharges are also considered waste streams. The tail gas from an acid gas removal process is an example of a waste stream in low/medium-Btu.

APPENDIX B - Metric Conversion Factors

To Convert From	To	Multiply By
	Acceleration	
ft/s^2	metre per second^2 (m/s^2)	3.048-000 E-01
	Area	
Acre (U.S. survey)[12]	meter^2 (m^2)	4.046 873 E+03
ft^2	meter^2 (m^2)	9.290 304 E-02
in^2	meter^2 (m^2)	6.451 600 E-04
yd^2	meter^2 (m^2)	8.361 274 E-01
	Energy (Includes Work)	
British thermal unit (mean)	joule (J)	1.055 87 E+03
Calorie (kilogram, mean)	joule (J)	4.190 02 E+03
kilocalorie (mean)	joule (J)	4.190 02 E+03
	Length	
foot	meter (m)	3.048 000 E-01
inch	meter (m)	2.540 000 E-02
yard	meter (m)	9.144 000 E-01
	Mass	
grain	kilogram (kg)	6.479 891 E-05
grain	kilogram (kg)	1.000 000 E-03
pound (lb avoirdupois)	kilogram (kg)	4.535 924 E-01
ton (metric)	kilogram (kg)	1.000 000 E+03
ton (short, 2000 lb)	kilogram (kg)	9.071 847 E+02
	Mass Per Unit Area	
lb/ft^2	kilogram per meter^2 (kg/m^2)	4.882 428 E+00

(continued)

To Convert From	To	Multiply By
	Mass Per Unit Length	
lb/ft	kilogram per meter (kg/m)	1.488 164 E+00
lb/in	kilogram per meter (kg/m)	1.785 797 E+01
	Mass Per Unit Time (Includes Flow)	
lb/h	kilogram per second (kg/s)	1.259 979 E-04
lb/min	kilogram per second (kg/s)	7.559 873 E-03
ton (short)/h	kilogram per second (kg/s)	2.519 958 E-01
	Mass Per Unit Volume (Includes Density & Mass Capacity)	
lb/ft^3	kilogram per meter^3 (kg/m^3)	1.601 846 E+01
lb/gal (U.S. liquid)	kilogram per meter^3 (kg/m^3)	1.198 264 E+02
lb/yd^3	kilogram per meter^3 (kg/m^3)	5.932 764 E-01
	Power	
Btu (thermochemical)/h	watt (W)	2.930 711 E-01
Btu (thermochemical)/h	watt (W)	2.928 751 E-01
cal (thermochemical)/ min	watt (W)	6.973 333 E-02
cal (thermochemical)/s	watt (W)	4.184 000 E+00
	Pressure or Stress (Force Per Unit Area)	
atmosphere (standard)	pascal (Pa)	1.013 250 E+05
foot of water (39.2°F)	pascal (Pa)	2.988 98 E+03
lbf/ft^2	pascal (Pa)	4.788 026 E+01
lbf/in^2 (psi)	pascal (Pa)	6.894 757 E+03
	Temperature	
degree Celsius	Kelvin (K)	$t_K = t_{°C} + 273.15$
degree Fahrenheit	degree Celsius	$t_{°C} = (t_{°F} - 32)/1.8$
degree Fahrenheit	Kelvin (K)	$t_K = (t_{°F} + 459.67)/1.8$
degree Rankine	Kelvin (K)	$t_K = t_{°R}/1.8$
Kelvin	degree Celsius	$t_{°C} = t_K - 273.15$

(continued)

To Convert From	To	Multiply By
	Velocity (Includes Speed)	
ft/h	meter per second (m/s)	8.466 667 E-05
ft/min	meter per second (m/s)	5.080 000 E-03
ft/s	meter per second (m/s)	3.048 000 E-01
in/s	meter per second (m/s)	2.540 000 E-02
	Viscosity	
centipoise	pascal second (Pa·s)	1.000 000 E-03
centistokes	$meter^2$ per second (m^2/s)	1.000 000 E-06
poise	pascal second (Pa·s)	1.000 000 E-01
stokes	$meter^2$ per second (m^2/s)	1.000 000 E-04
	Volume (Includes Capacity)	
acre-foot (U.S. survey)	$meter^3$ (m^3)	1.233 489 E+03
barrel (oil, 42 gal)	$meter^3$ (m^3)	1.589 873 E-01
ft^3	$meter^3$ (m^3)	2.831 685 E-02
gallon (U.S. liquid)	$meter^3$ (m^3)	3.785 412 E-03
litre*	$meter^3$ (m^3)	1.000 000 E-03
	Volume Per Unit Time (Includes Flow)	
ft^3/min	$meter^3$ per second (m^3/s)	4.719 474 E-04
ft^3/s	$meter^3$ per second (m^3/s)	2.831 685 E-02
gal (U.S. liquid/day)	$meter^3$ per second (m^3/s)	4.381 264 E-08
gal (U.S. liquid/min)	$meter^3$ per second (m^3/s)	6.309 020 E-05

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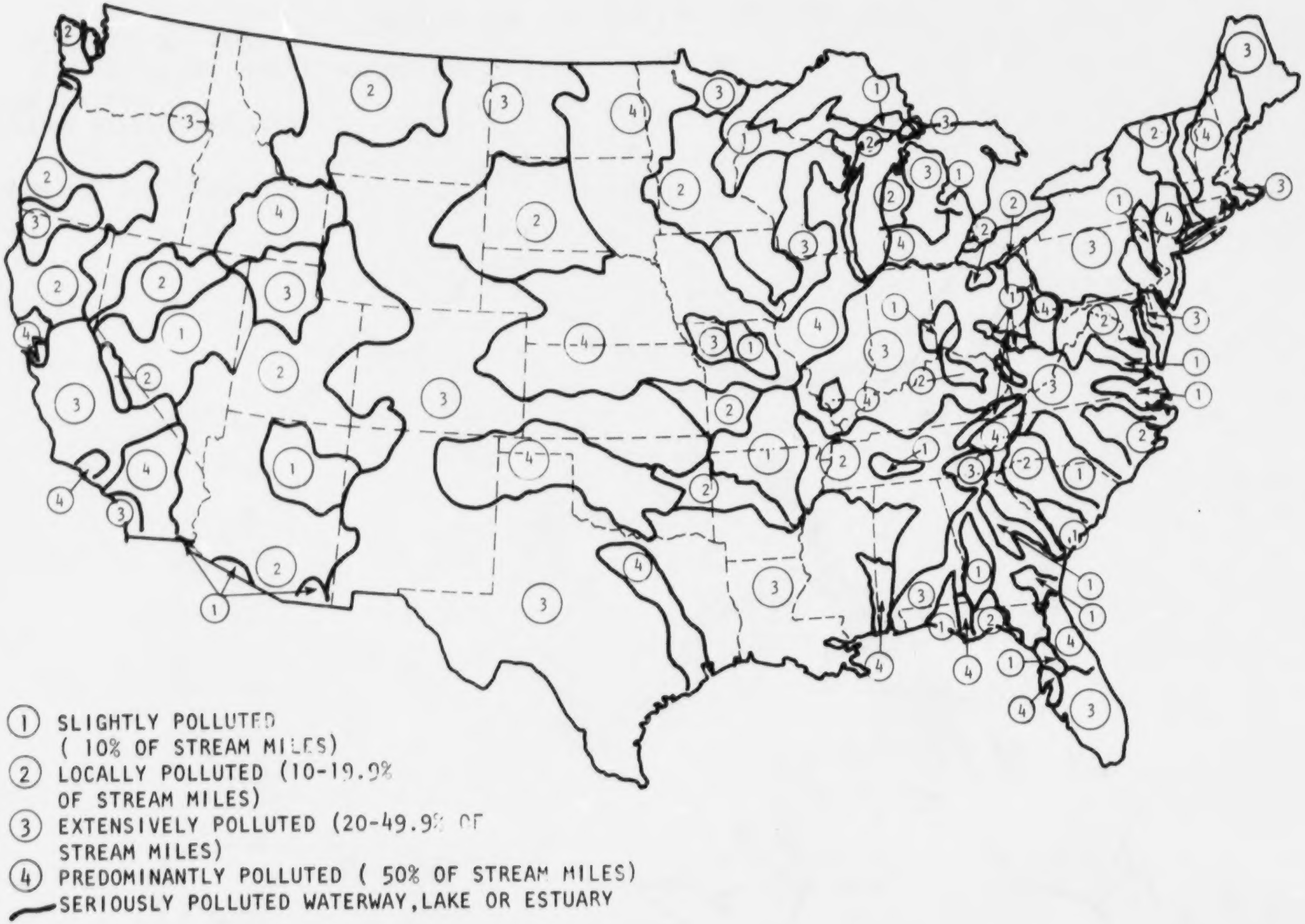
*In 1964 the General Conference on Weights and Measures adopted the name litre as a special name for the cubic decimetre. Prior to this decision the litre differed slightly (previous value, 1.000028 dm^3) and in expression of precision volume measurement this fact must be kept in mind.

APPENDIX C - Quality of Rivers of the United States (148,149)

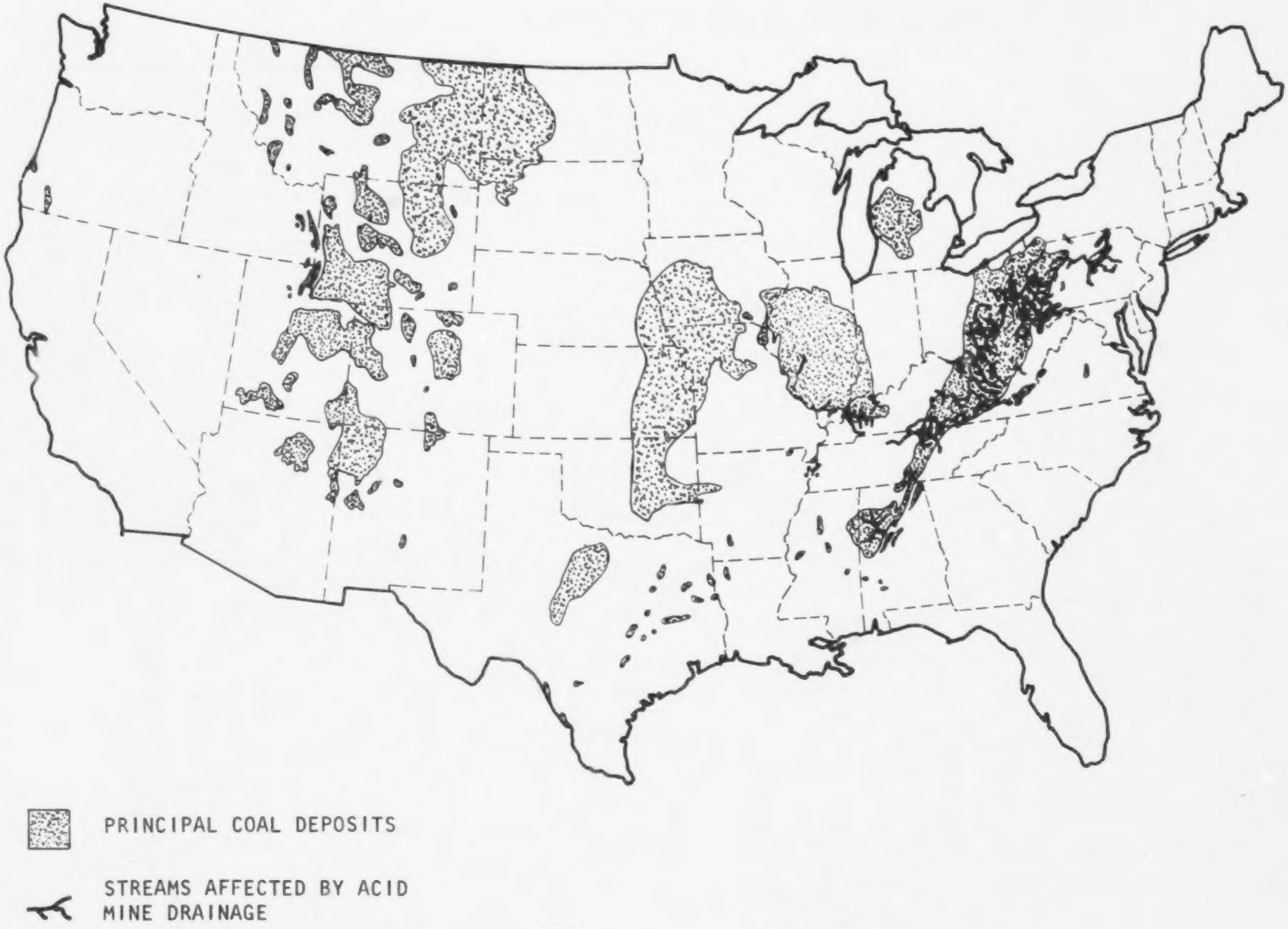
The maps in this subsection illustrate regional water quality parameters. Some are reprinted with the permission of the United States Geological Survey.



① SLIGHTLY POLLUTED (10% OF STREAM MILES)
② LOCALLY POLLUTED (10-19.9% OF STREAM MILES)
③ EXTENSIVELY POLLUTED (20-49.9% OF STREAM MILES)
④ PREDOMINANTLY POLLUTED (50% OF STREAM MILES)
SERIOUSLY POLLUTED WATERWAY, LAKE OR ESTUARY

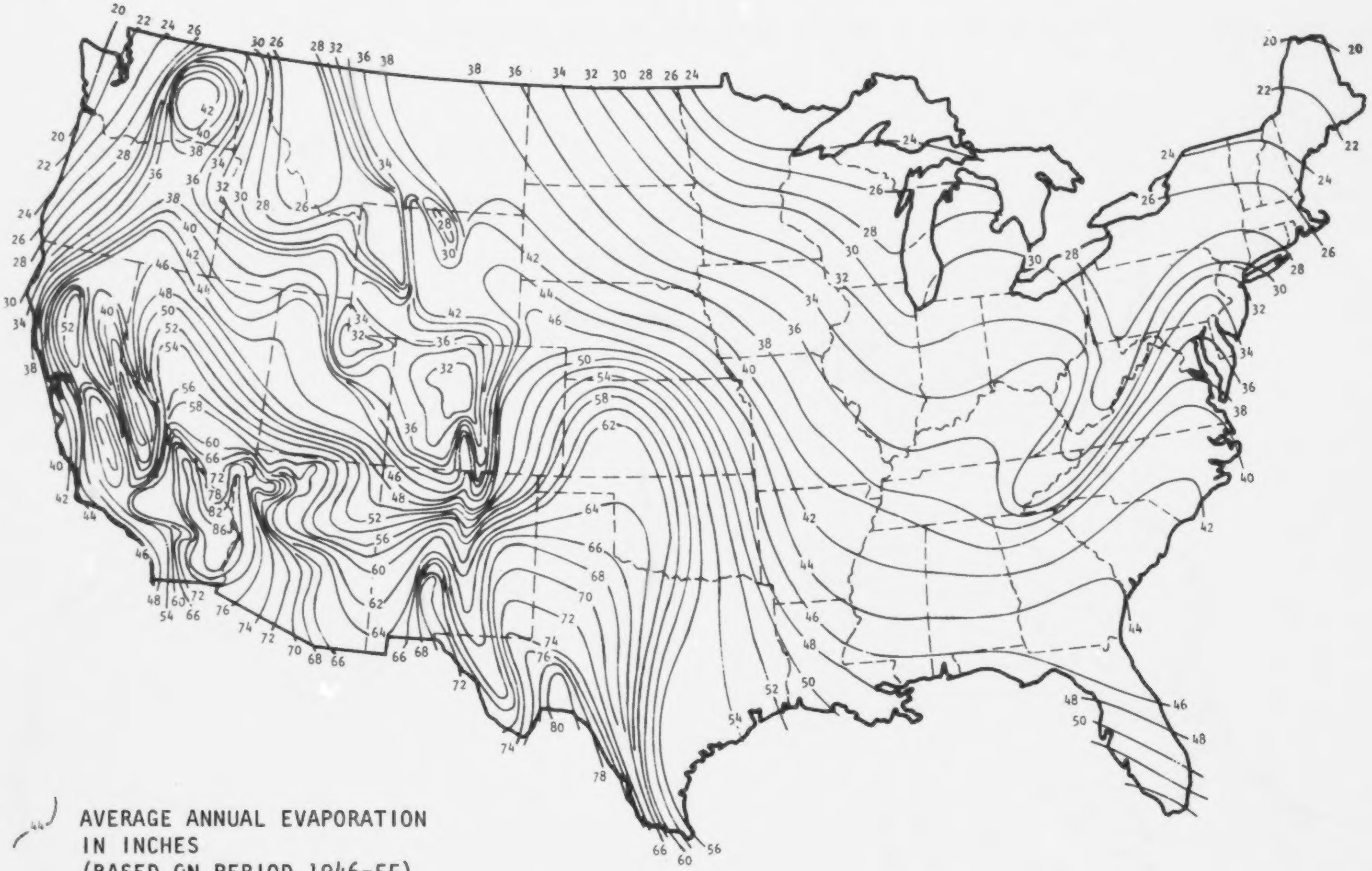
SOURCE: ENVIRONMENTAL PROTECTION AGENCY, 1970

Figure 74. Principal areas of water pollution (148).


▨ PRINCIPAL COAL DEPOSITS
STREAMS AFFECTED BY ACID MINE DRAINAGE

SOURCE: U.S. GEOLOGICAL SURVEY, HYDROL INV. ATLAS HA-198, 1965

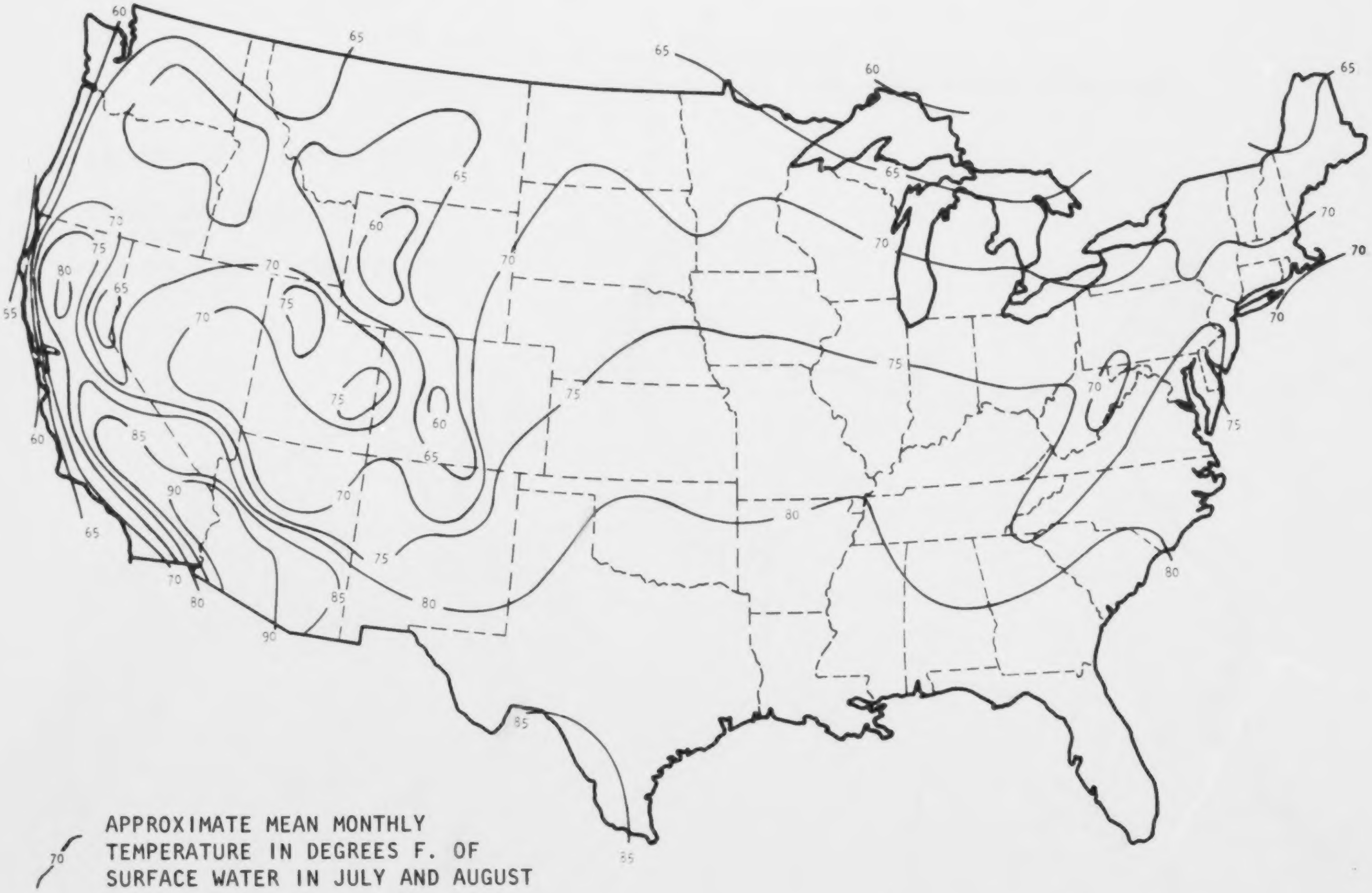
Figure 75. Acid mine drainage (148).



AVERAGE ANNUAL EVAPORATION
IN INCHES
(BASED ON PERIOD 1946-55)

SOURCE: U.S. WEATHER BUREAU

Figure 76. Evaporation from open-water surfaces (average annual) (148)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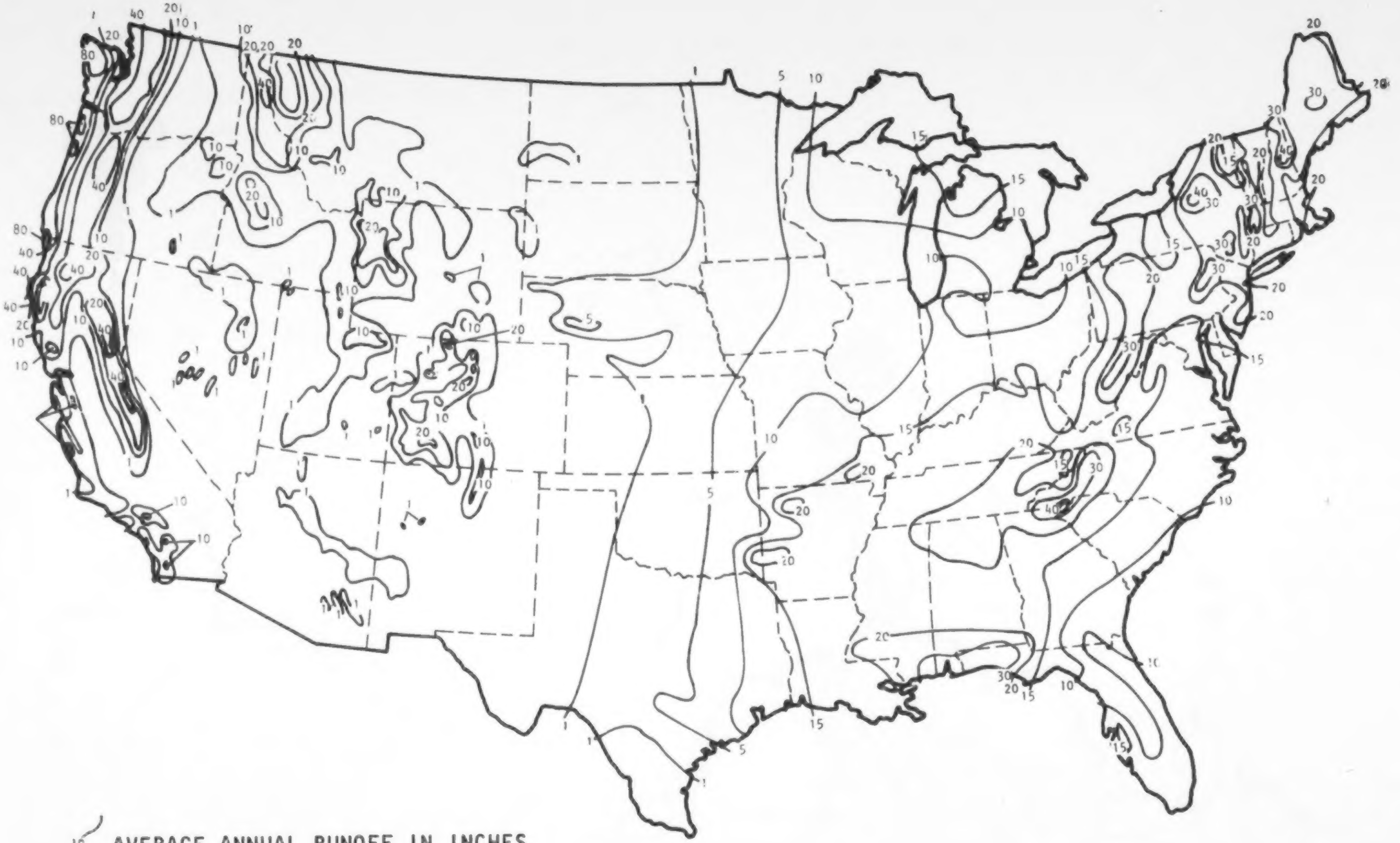
APPROXIMATE MEAN MONTHLY TEMPERATURE IN DEGREES F. OF SURFACE WATER IN JULY AND AUGUST

SOURCE: U.S. GEOLOGICAL SURVEY

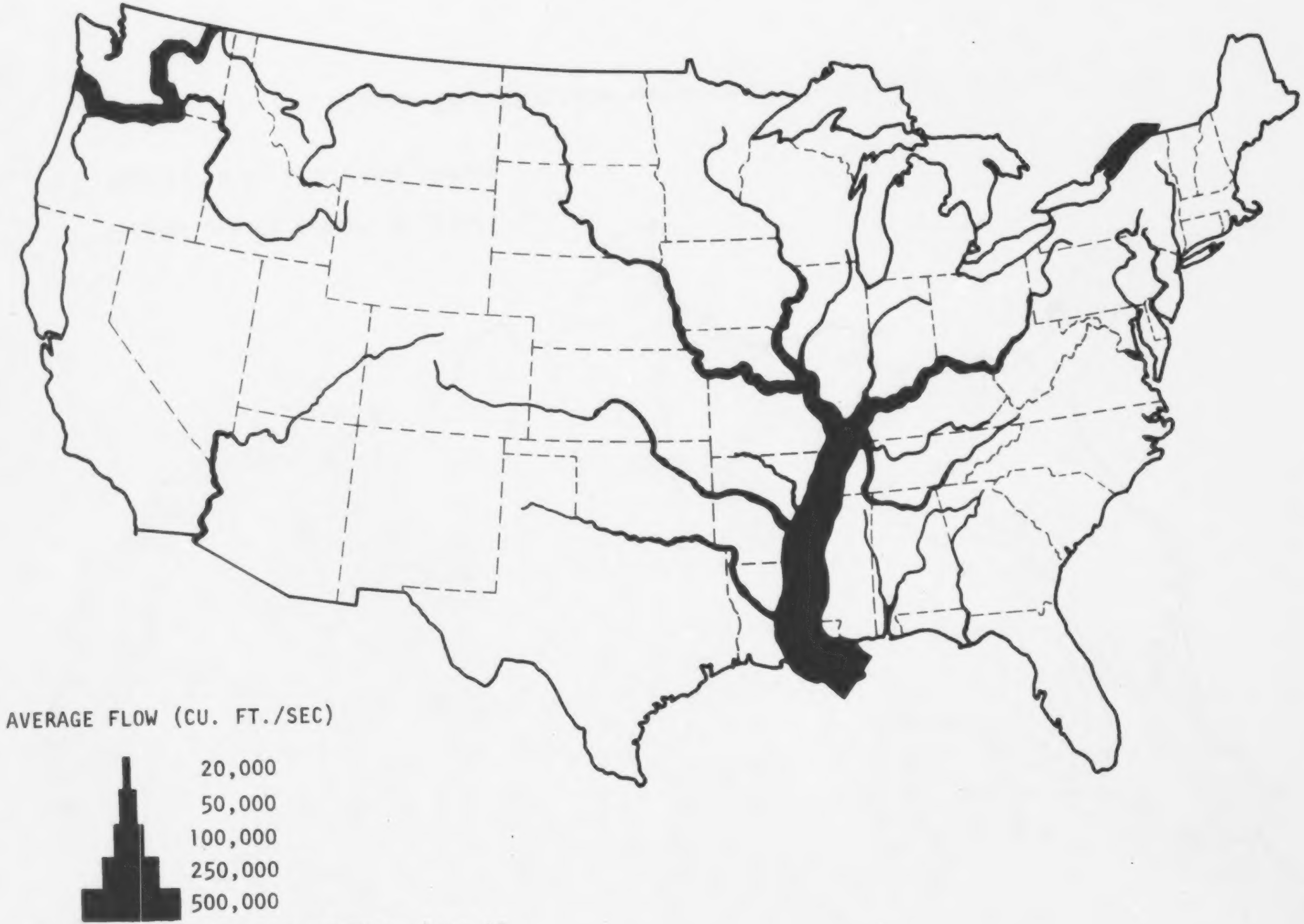
Figure 77. Temperature of surface water - July and August (148)



10 AVERAGE ANNUAL RUNOFF IN INCHES

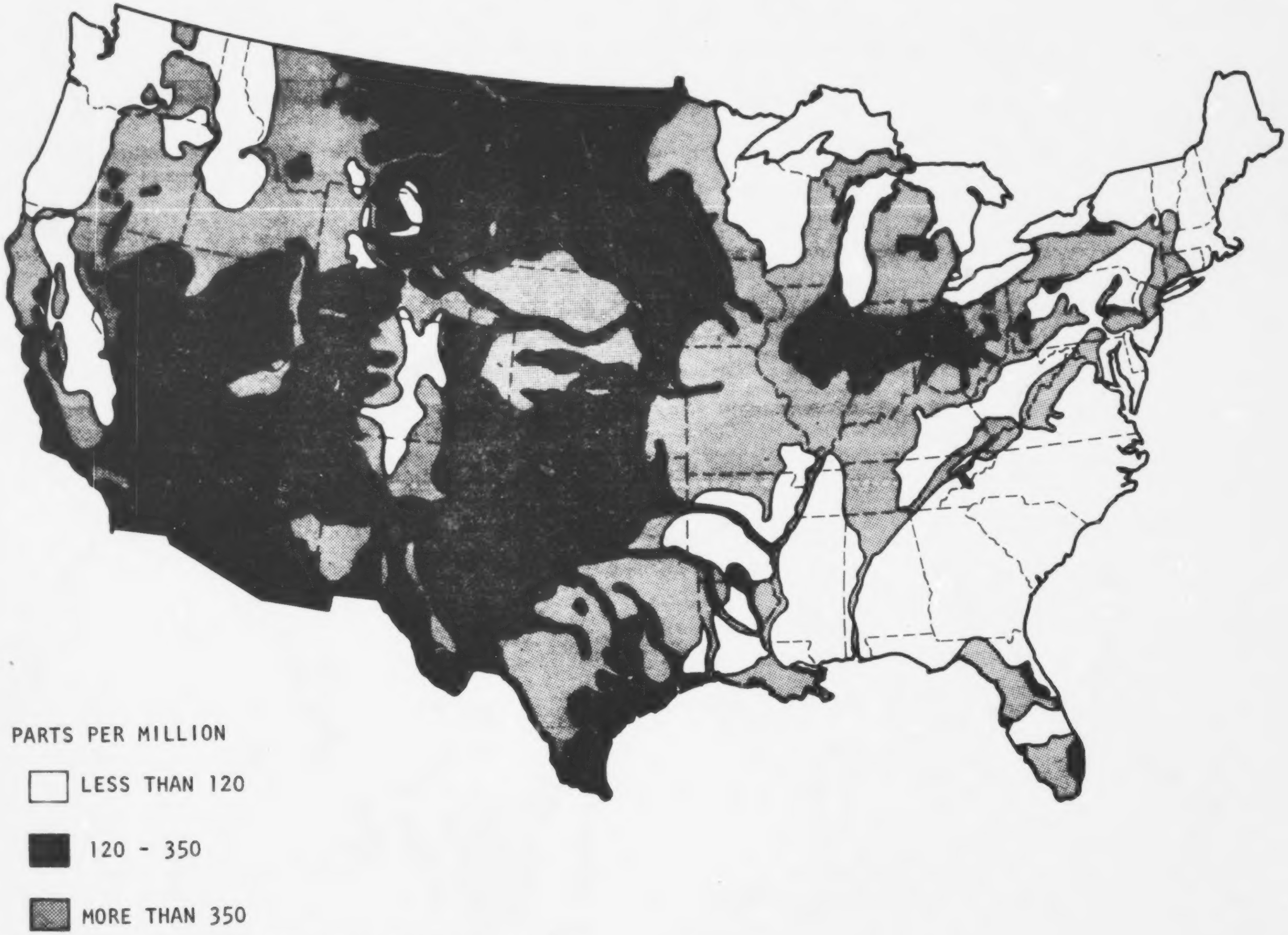
SOURCE: U.S. GEOLOGICAL SURVEY

Figure 78. Surface-water runoff (average annual) (148)


AVERAGE FLOW (CU. FT./SEC)
20,000
50,000
100,000
250,000
500,000

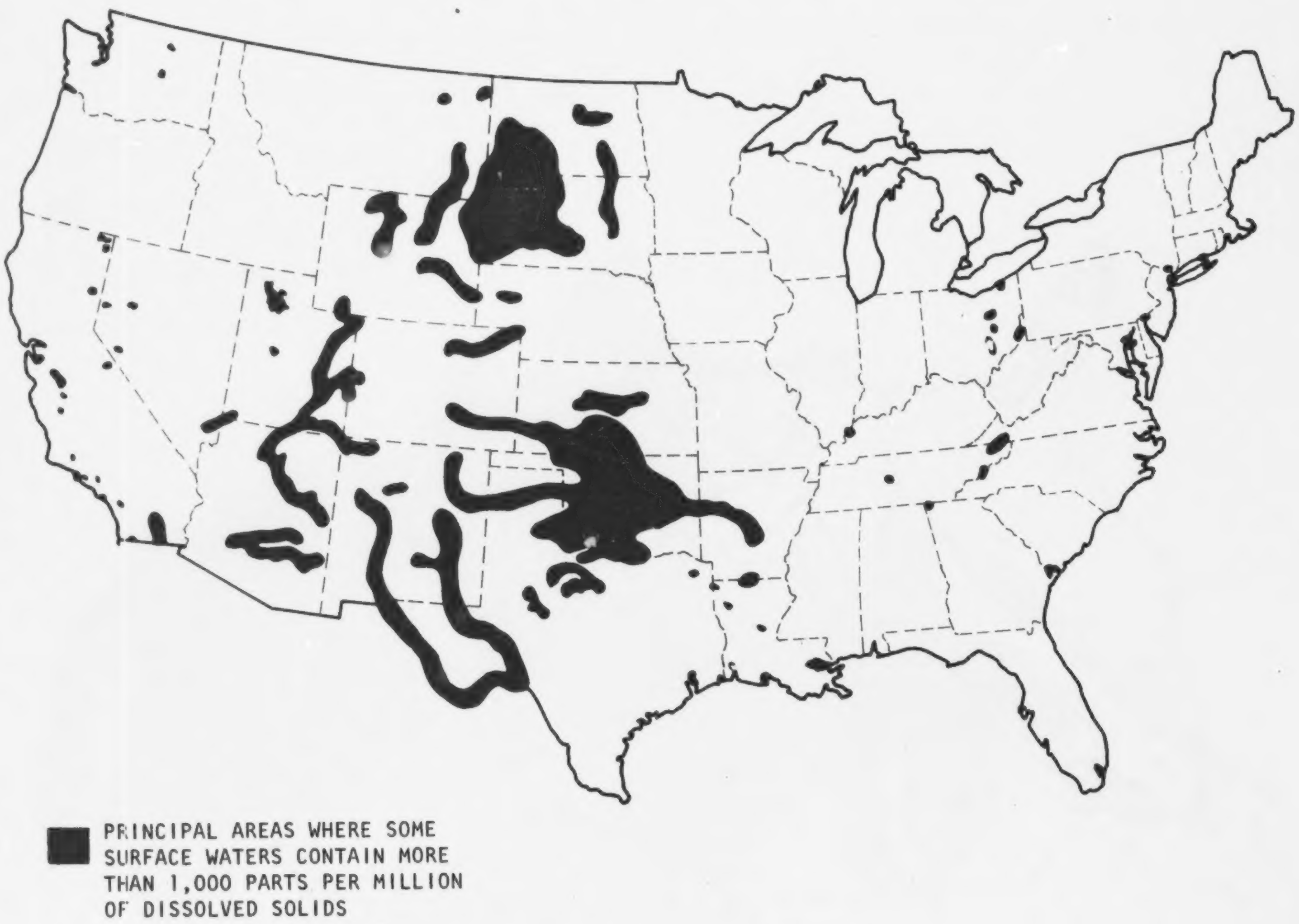
SOURCE: U.S. GEOLOGICAL SURVEY, CIRC.44

Figure 79. Flow of large rivers (148)


PARTS PER MILLION
☐ LESS THAN 120
■ 120 - 350
▨ MORE THAN 350

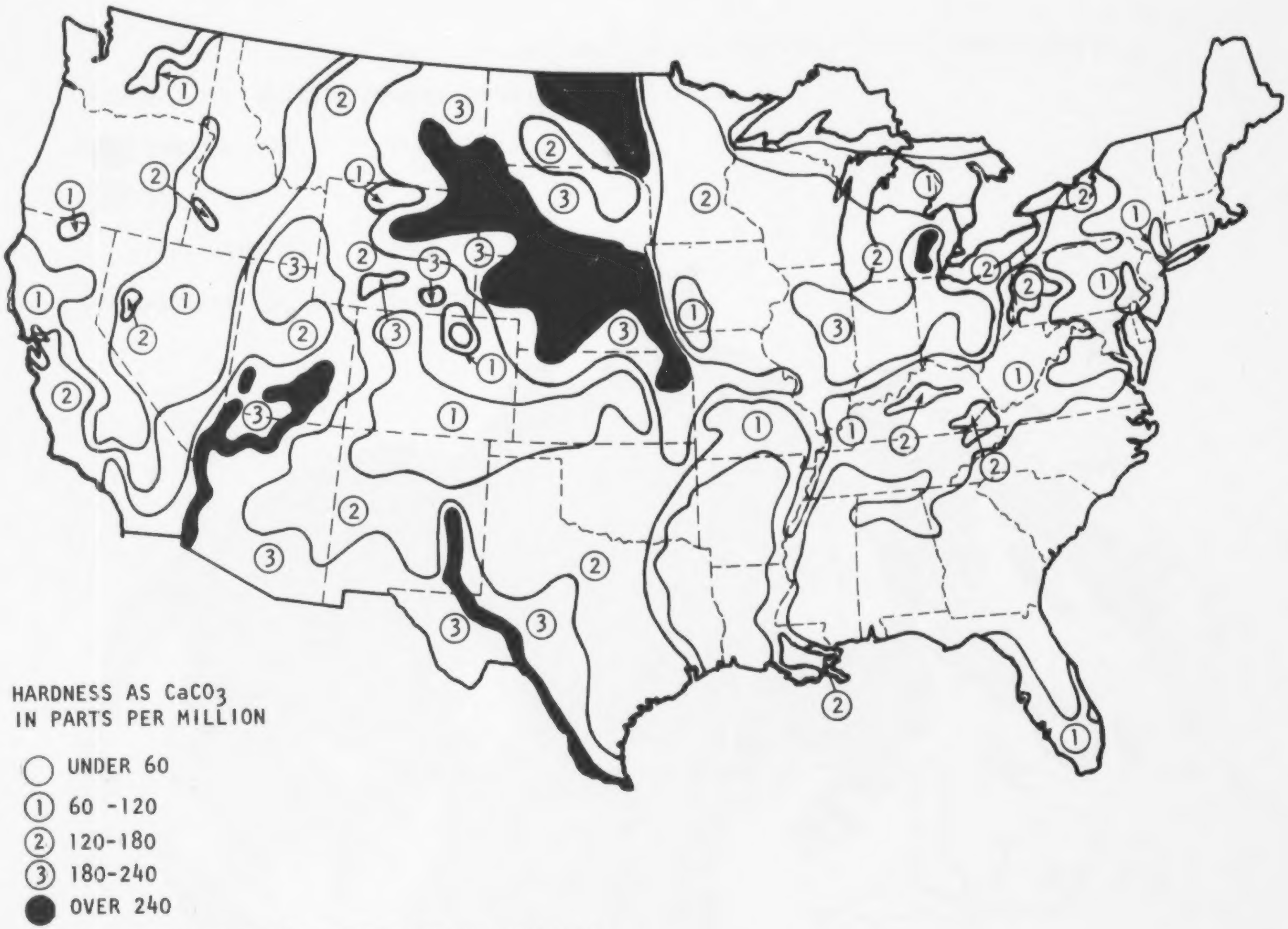
SOURCE: U.S. WATER RESOURCES COUNCIL, 1968

Figure 80. Dissolved solids content of surface water (148)


PRINCIPAL AREAS WHERE SOME SURFACE WATERS CONTAIN MORE THAN 1,000 PARTS PER MILLION OF DISSOLVED SOLIDS

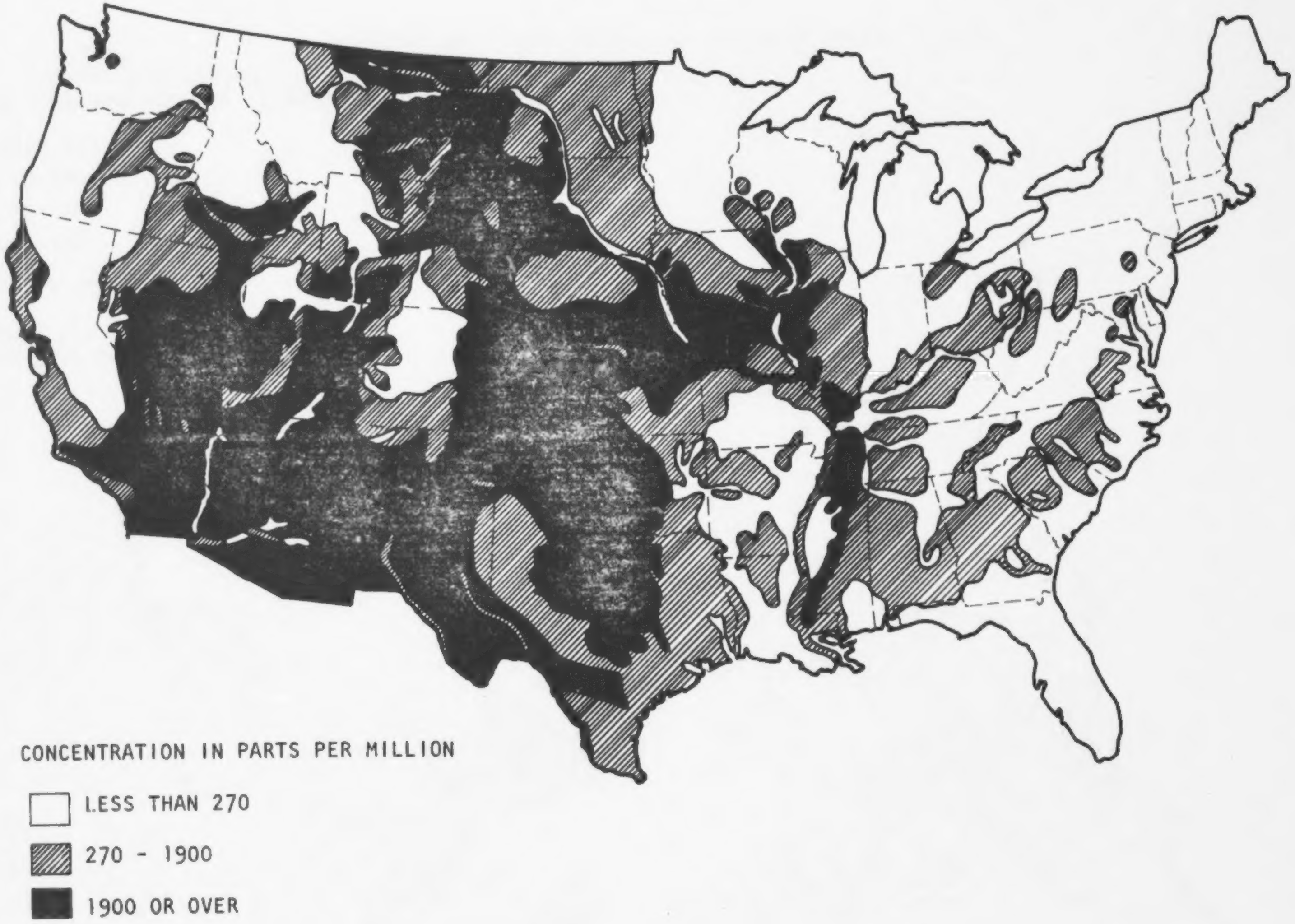
SOURCE: U.S. GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1374

Figure 81. Saline surface-water (148)


HARDNESS AS CaCO3
IN PARTS PER MILLION
○ UNDER 60
① 60 -120
② 120-180
③ 180-240
● OVER 240

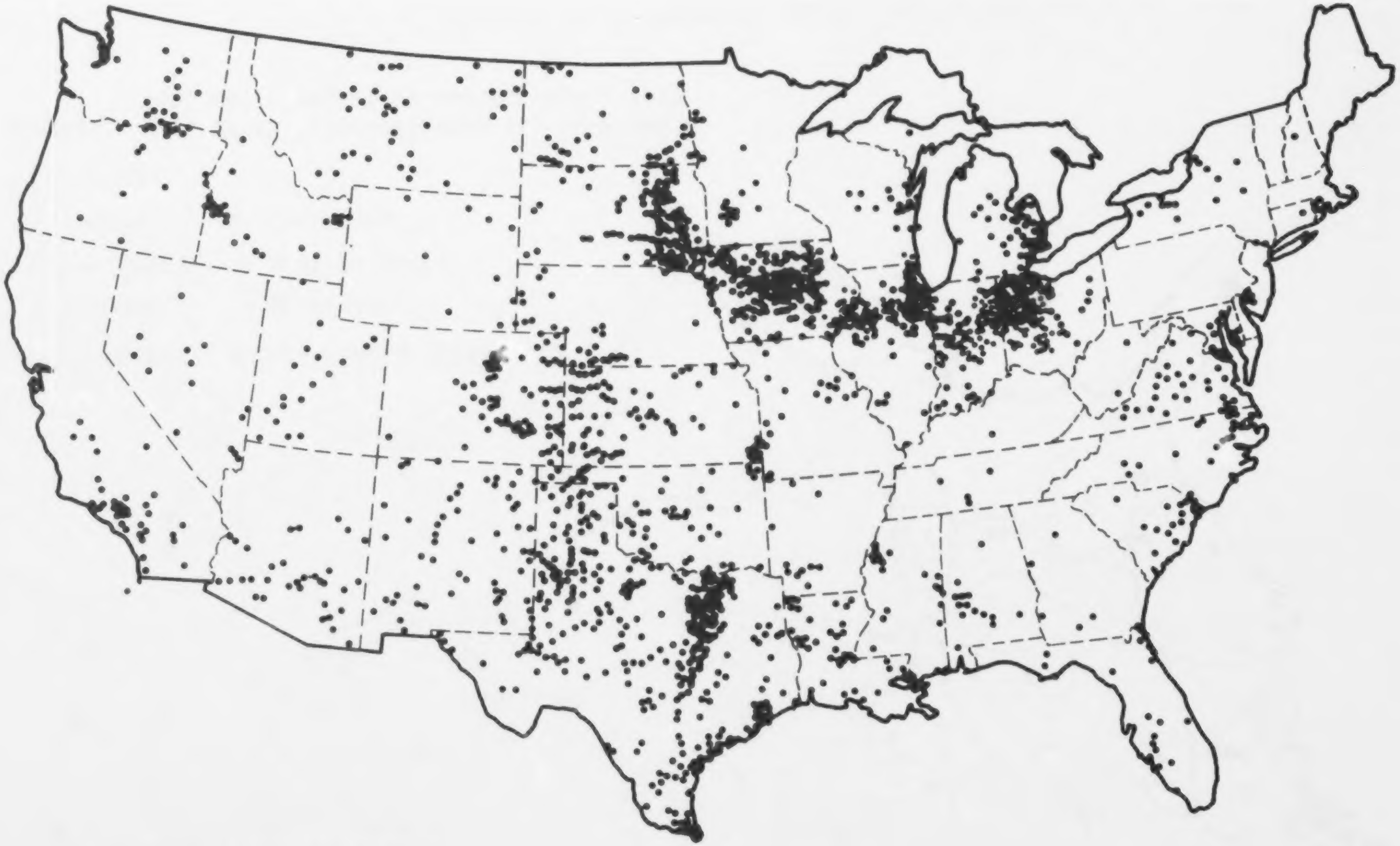
SOURCE: ACKEMAN AND LÖF TECHNOLOGY IN AMERICAN WATER DEVELOPMENT

Figure 82. Hardness of surface water (148)


CONCENTRATION IN PARTS PER MILLION
☐ LESS THAN 270
▨ 270 - 1900
■ 1900 OR OVER

SOURCE: U.S. WATER RESOURCES COUNCIL, 1968

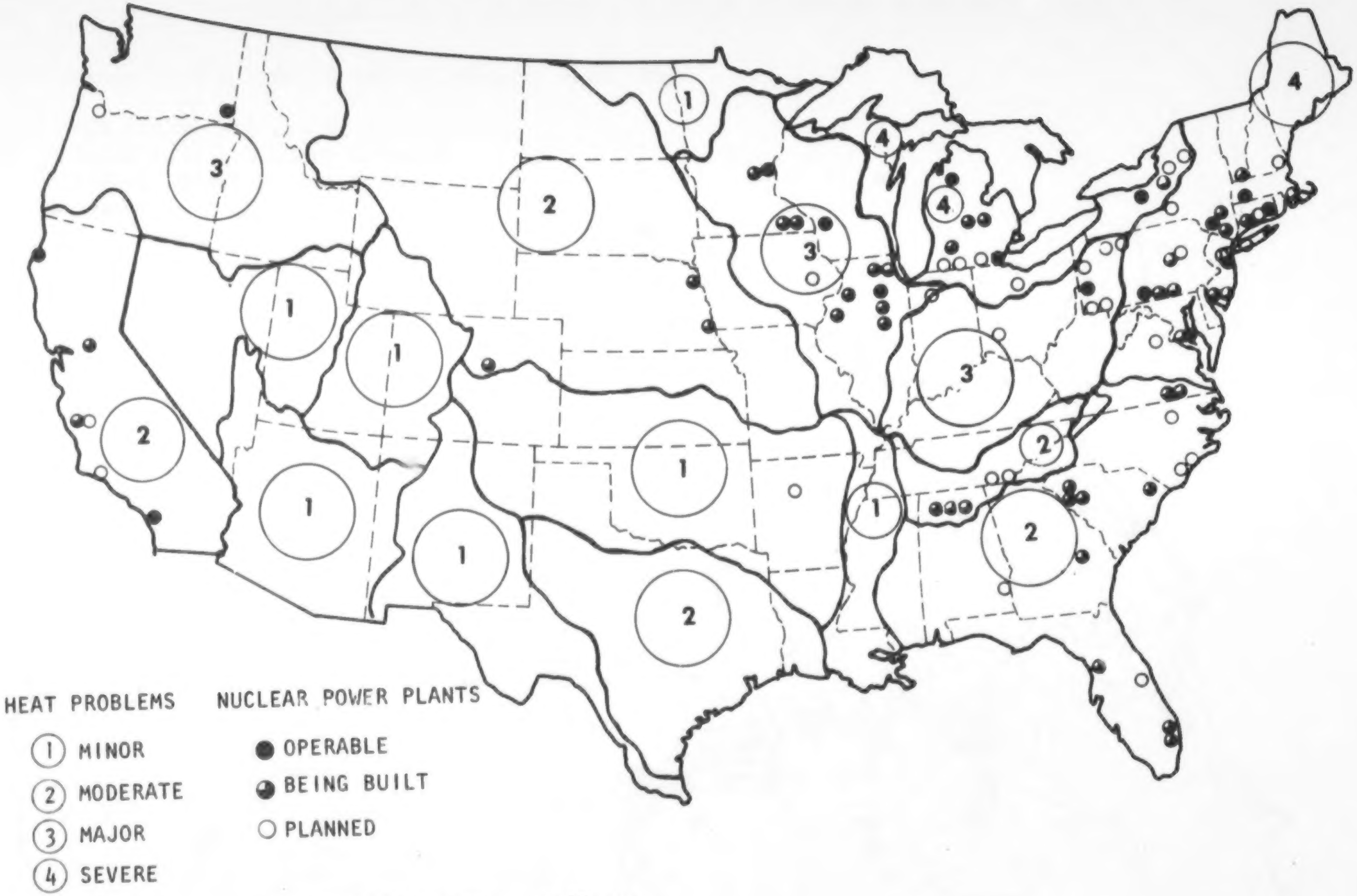
Figure 83. Concentration of sediment in streams (148)



● COMMUNITY WITH AT LEAST A SINGLE SOURCE OF DRINKING WATER WITH A NATURAL FLUORIDE CONTENT OF 0.7 PPM OR MORE

SOURCE: U.S. PUBLIC HEALTH SERVICE, PUBL. 655

Figure 84. Natural fluoride in water supplies (148)


HEAT PROBLEMS
① MINOR
② MODERATE
③ MAJOR
④ SEVERE
NUCLEAR POWER PLANTS
● OPERABLE
◕ BEING BUILT
○ PLANNED
1
2
3
4

SOURCES: U.S. WATER RESOURCES COUNCIL, 1968 AND
FED. WATER POLLUTION CONTROL ADM., 1970

Figure 85. Thermal pollution (148)

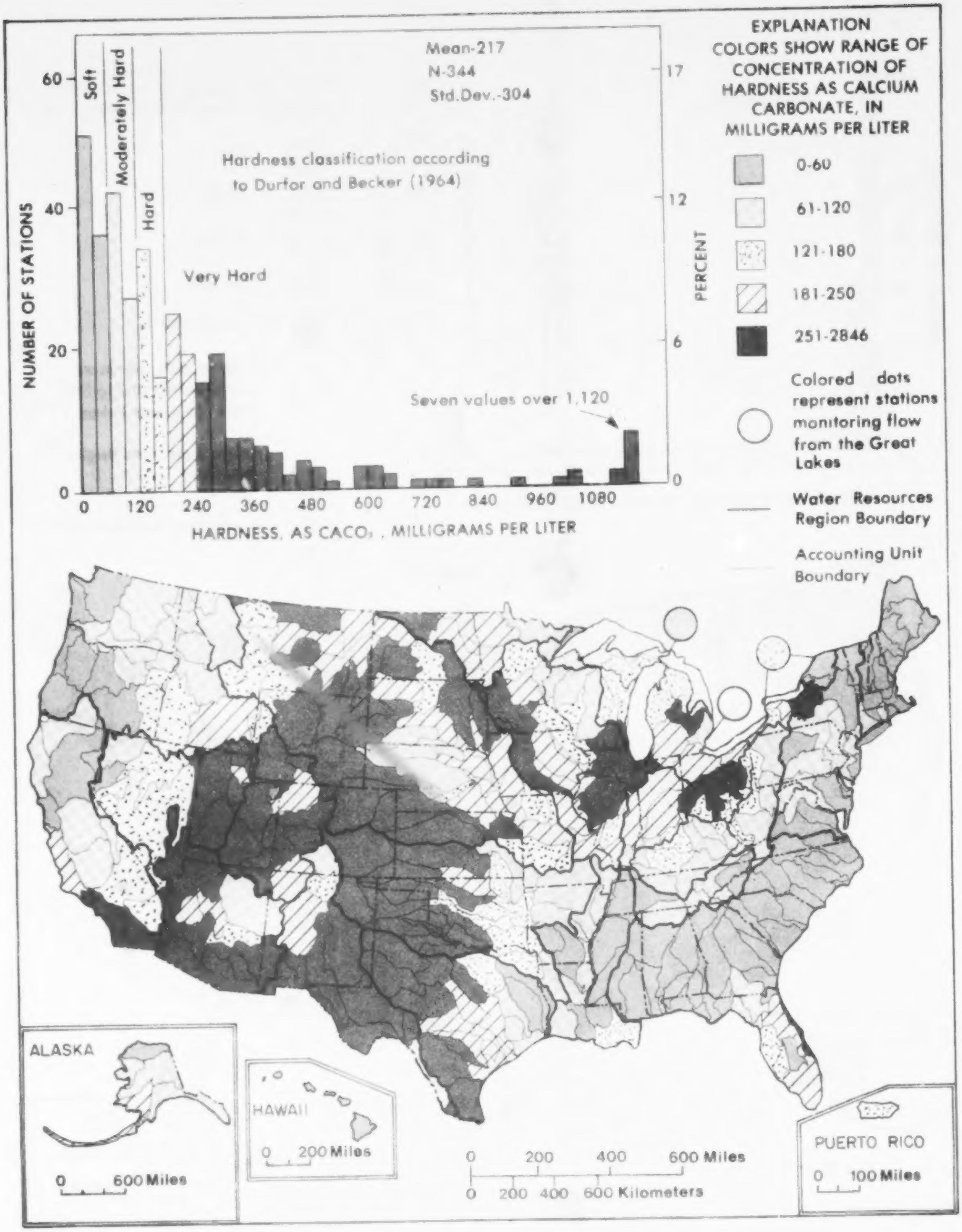

Mean-217
N-344
Std.Dev.-304
Soft
Moderately Hard
Hard
Very Hard
Hardness classification according to Durfor and Becker (1964)
Seven values over 1,120
NUMBER OF STATIONS
PERCENT
0
20
40
60
6
12
17
0
120
240
360
480
600
720
840
960
1080
HARDNESS, AS CACO₃, MILLIGRAMS PER LITER
EXPLANATION
COLORS SHOW RANGE OF CONCENTRATION OF HARDNESS AS CALCIUM CARBONATE, IN MILLIGRAMS PER LITER
0-60
61-120
121-180
181-250
251-2846
Colored dots represent stations monitoring flow from the Great Lakes
Water Resources Region Boundary
Accounting Unit Boundary
ALASKA
0 600 Miles
HAWAII
0 200 Miles
0 200 400 600 Miles
0 200 400 600 Kilometers
PUERTO RICO
0 100 Miles

Figure 86. Mean hardness as calcium carbonate at NASQAN stations during 1975 water year (149)

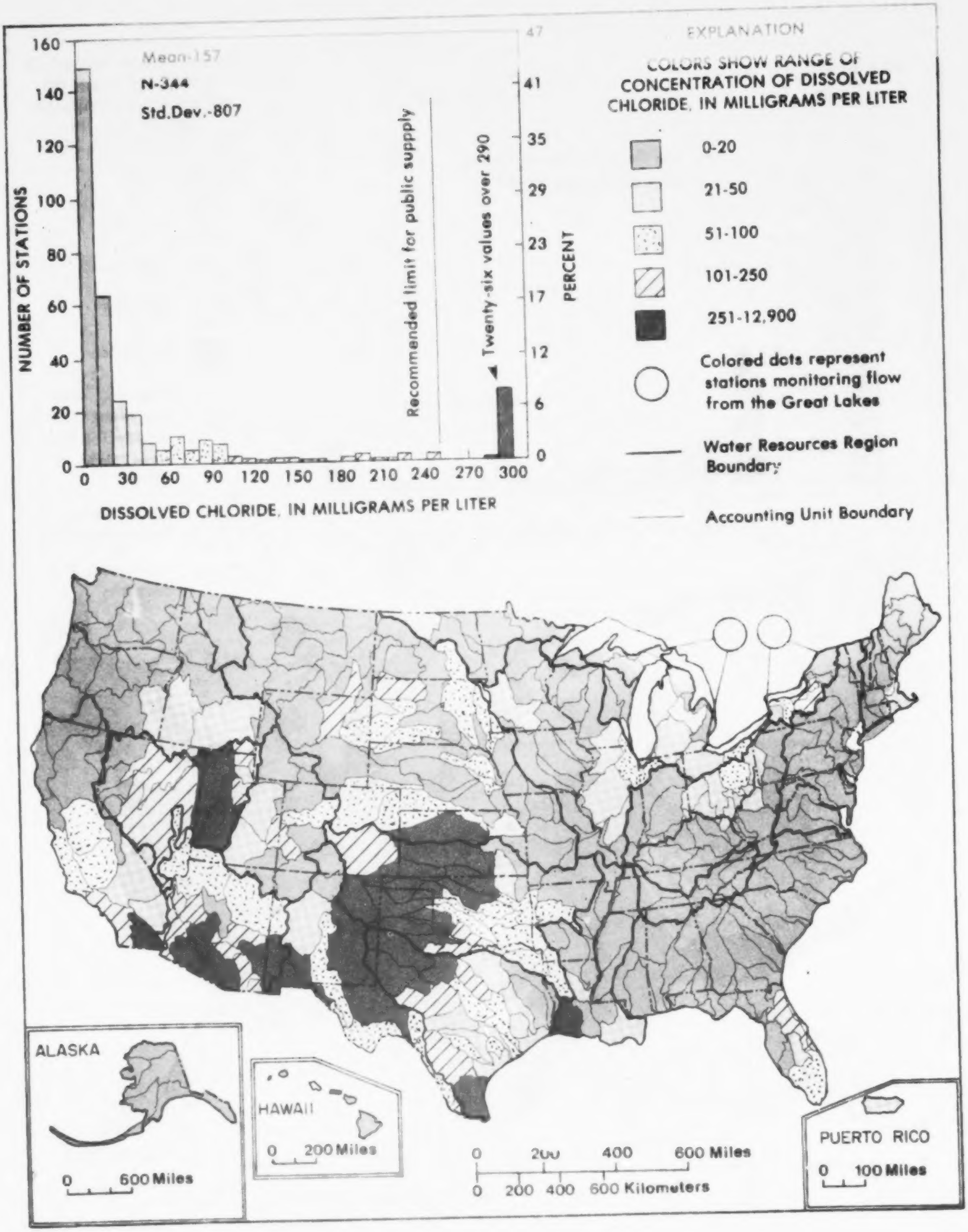
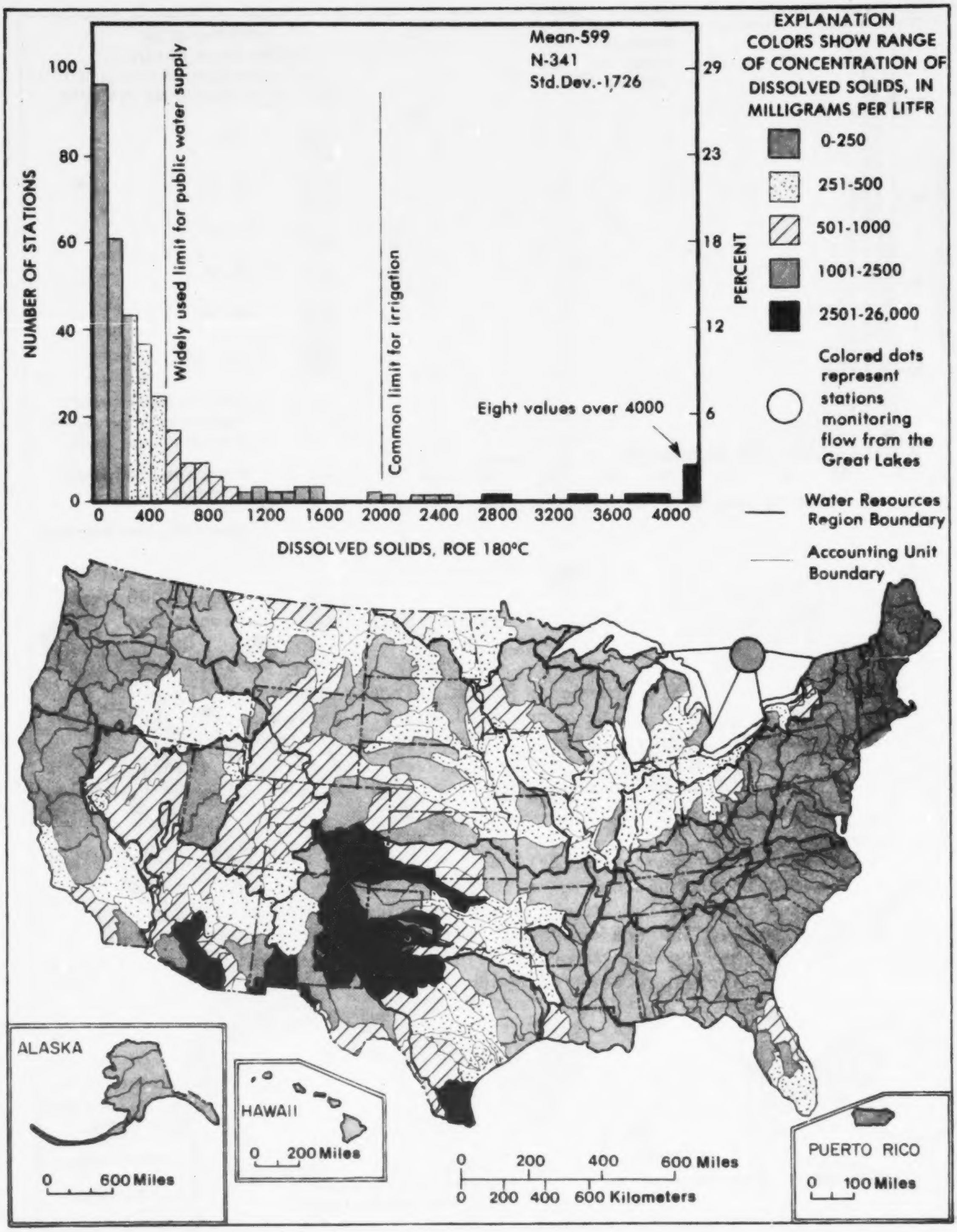

Mean-157
N-344
Std.Dev.-807
NUMBER OF STATIONS
160
140
120
100
80
60
40
20
0
0 30 60 90 120 150 180 210 240 270 300
DISSOLVED CHLORIDE, IN MILLIGRAMS PER LITER
Recommended limit for public suppply
Twenty-six values over 290
PERCENT
47
41
35
29
23
17
12
6
0
EXPLANATION
COLORS SHOW RANGE OF CONCENTRATION OF DISSOLVED CHLORIDE, IN MILLIGRAMS PER LITER
0-20
21-50
51-100
101-250
251-12,900
Colored dots represent stations monitoring flow from the Great Lakes
Water Resources Region Boundary
Accounting Unit Boundary
ALASKA
0 600 Miles
HAWAII
0 200 Miles
0 200 400 600 Miles
0 200 400 600 Kilometers
PUERTO RICO
0 100 Miles

Figure 87. Mean concentration of dissolved chloride at NASQAN stations during 1975 water year (149)



Mean-599
N-341
Std.Dev.-1726
NUMBER OF STATIONS
PERCENT
Widely used limit for public water supply
Common limit for irrigation
Eight values over 4000
DISSOLVED SOLIDS, ROE 180°C
0
20
40
60
80
100
6
12
18
23
29
0
400
800
1200
1600
2000
2400
2800
3200
3600
4000
EXPLANATION
COLORS SHOW RANGE OF CONCENTRATION OF DISSOLVED SOLIDS, IN MILLIGRAMS PER LITER
0-250
251-500
501-1000
1001-2500
2501-26,000
Colored dots represent stations monitoring flow from the Great Lakes
Water Resources Region Boundary
Accounting Unit Boundary
ALASKA
0 600 Miles
HAWAII
0 200 Miles
0 200 400 600 Miles
0 200 400 600 Kilometers
PUERTO RICO
0 100 Miles

Figure 88. Mean concentration of dissolved solids measured as residue on evaporation (ROE) at 180°C at NASQAN stations during 1975 water year (149)

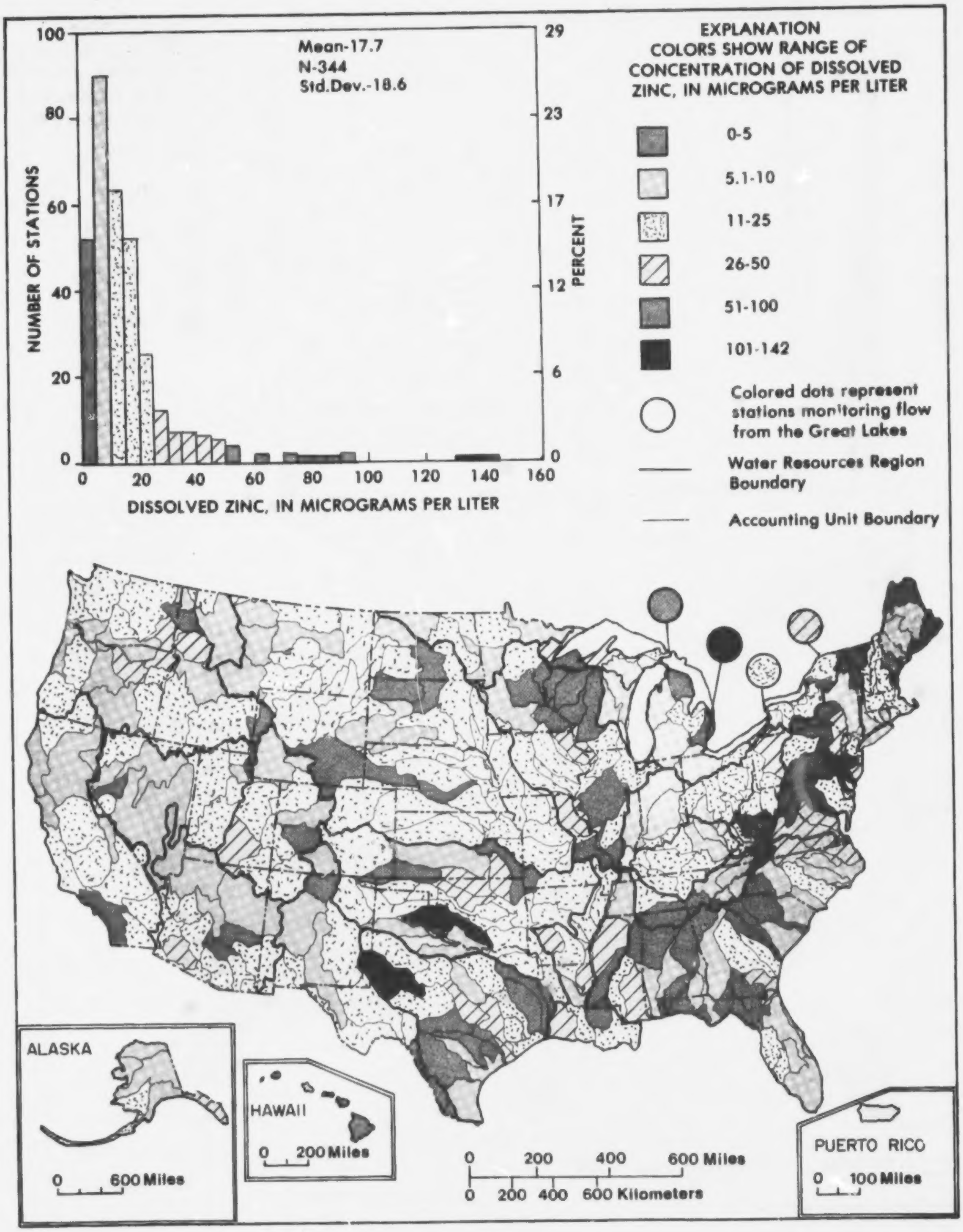

Mean-17.7
N-344
Std.Dev.-18.6
NUMBER OF STATIONS
PERCENT
100
80
60
40
20
0
29
23
17
12
6
0
0
20
40
60
80
100
120
140
160
DISSOLVED ZINC, IN MICROGRAMS PER LITER
EXPLANATION
COLORS SHOW RANGE OF CONCENTRATION OF DISSOLVED ZINC, IN MICROGRAMS PER LITER
0-5
5.1-10
11-25
26-50
51-100
101-142
Colored dots represent stations monitoring flow from the Great Lakes
Water Resources Region Boundary
Accounting Unit Boundary
ALASKA
0 600 Miles
HAWAII
0 200 Miles
0 200 400 600 Miles
0 200 400 600 Kilometers
PUERTO RICO
0 100 Miles

Figure 89. Mean concentration of dissolved zinc at NASQAN stations during 1975 water year (149)

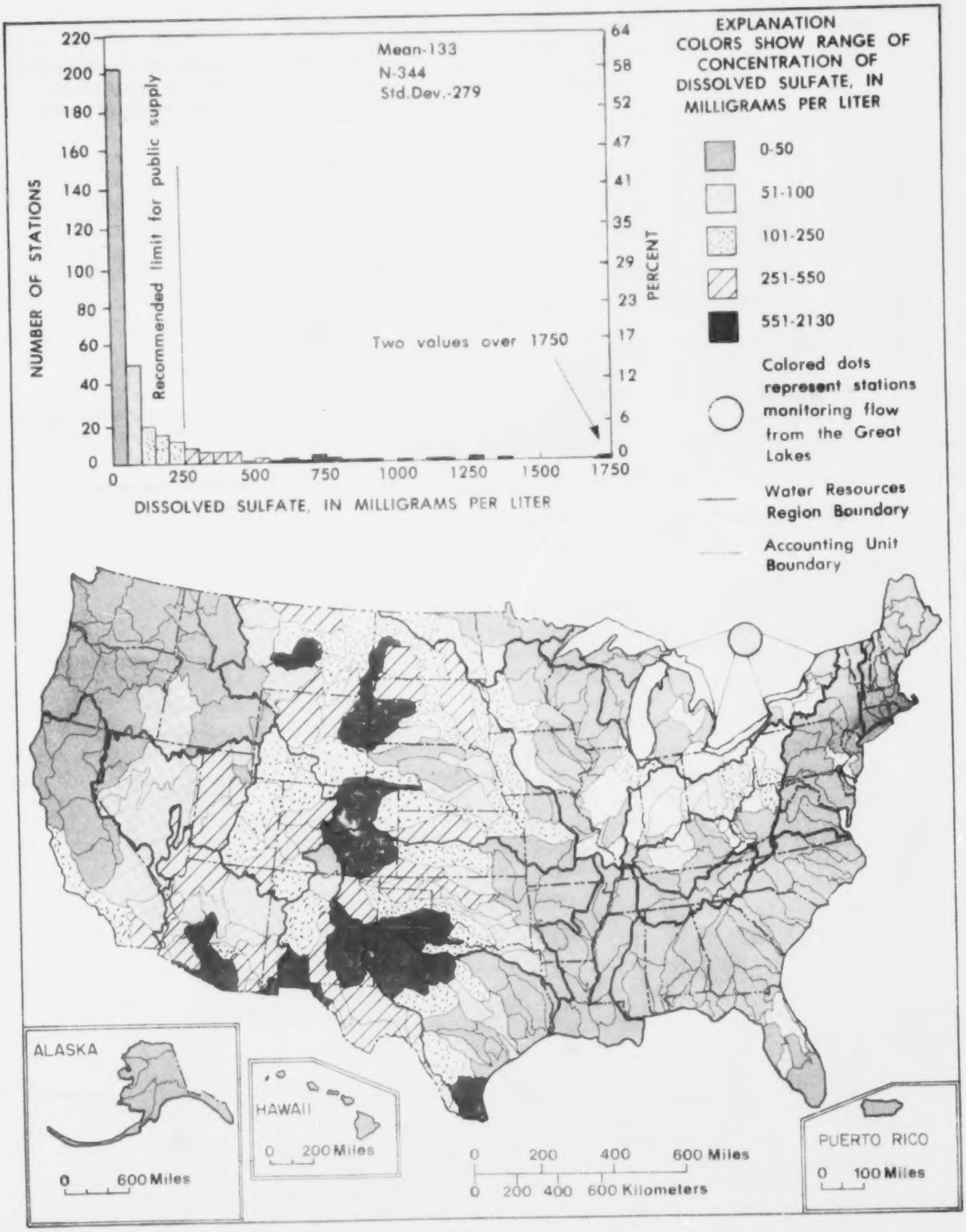

Mean-133
N-344
Std.Dev.-279
Recommended limit for public supply
Two values over 1750
NUMBER OF STATIONS
PERCENT
DISSOLVED SULFATE, IN MILLIGRAMS PER LITER
220
200
180
160
140
120
100
80
60
40
20
0
64
58
52
47
41
35
29
23
17
12
6
0
0
250
500
750
1000
1250
1500
1750
EXPLANATION
COLORS SHOW RANGE OF CONCENTRATION OF DISSOLVED SULFATE, IN MILLIGRAMS PER LITER
0-50
51-100
101-250
251-550
551-2130
Colored dots represent stations monitoring flow from the Great Lakes
Water Resources Region Boundary
Accounting Unit Boundary
ALASKA
0 600 Miles
HAWAII
0 200 Miles
0 200 400 600 Miles
0 200 400 600 Kilometers
PUERTO RICO
0 100 Miles

Figure 90. Mean concentration of dissolved sulfate at NASQAN stations during 1975 water year (149)

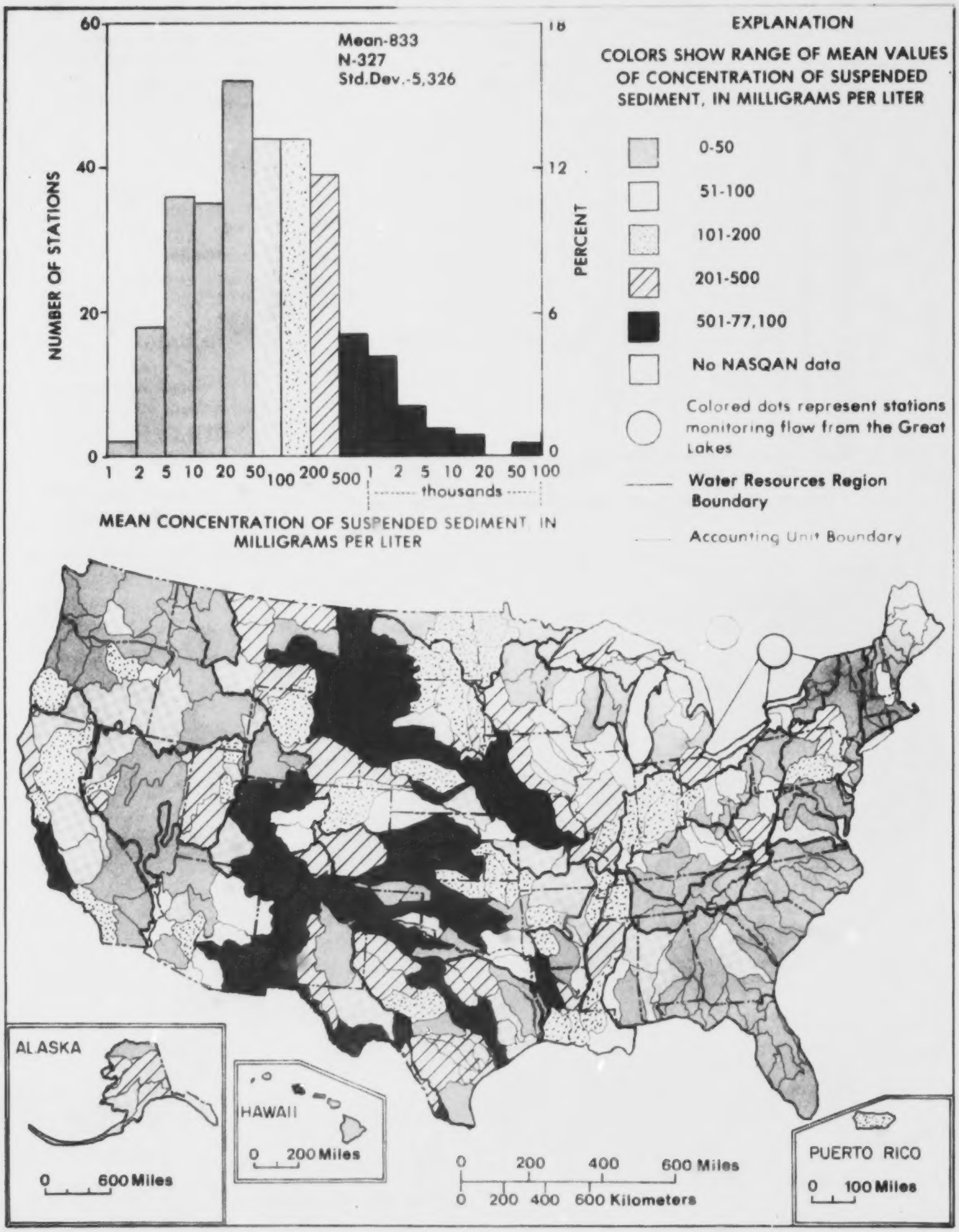
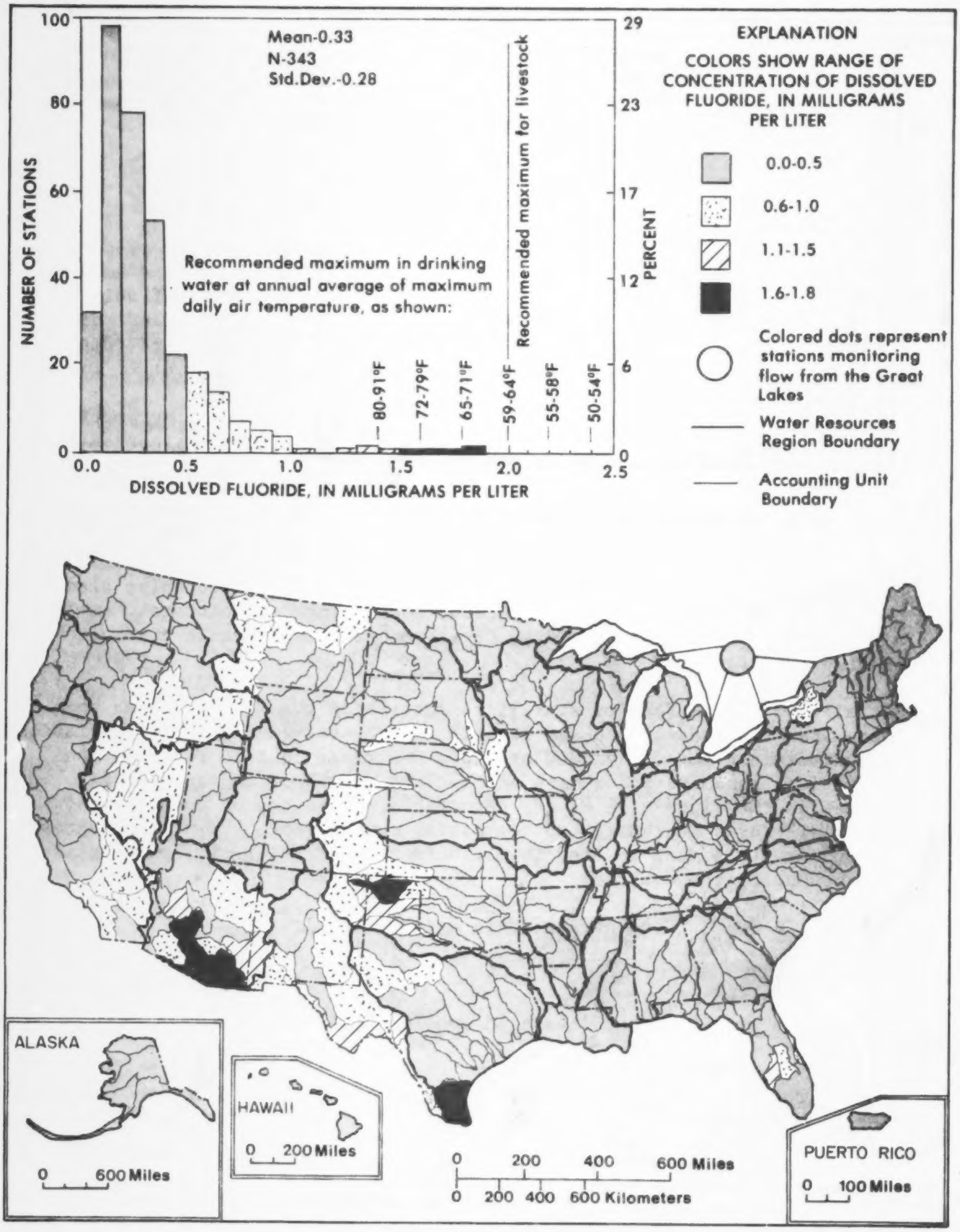

Mean-833
N-327
Std.Dev.-5,326
NUMBER OF STATIONS
PERCENT
60
40
20
0
18
12
6
0
1 2 5 10 20 50 100 200 500 1 2 5 10 20 50 100
thousands
MEAN CONCENTRATION OF SUSPENDED SEDIMENT, IN MILLIGRAMS PER LITER
EXPLANATION
COLORS SHOW RANGE OF MEAN VALUES OF CONCENTRATION OF SUSPENDED SEDIMENT, IN MILLIGRAMS PER LITER
0-50
51-100
101-200
201-500
501-77,100
No NASQAN data
Colored dots represent stations monitoring flow from the Great Lakes
Water Resources Region Boundary
Accounting Unit Boundary
ALASKA
0 600 Miles
HAWAII
0 200 Miles
0 200 400 600 Miles
0 200 400 600 Kilometers
PUERTO RICO
0 100 Miles

Figure 91. Mean concentration of suspended sediment at NASQAN stations during 1975 water year (149)



Mean-0.33
N-343
Std.Dev.-0.28
NUMBER OF STATIONS
100
80
60
40
20
0
29
23
17
12
6
0
PERCENT
Recommended maximum in drinking water at annual average of maximum daily air temperature, as shown:
80-91°F
72-79°F
65-71°F
59-64°F
55-58°F
50-54°F
Recommended maximum for livestock
0.0
0.5
1.0
1.5
2.0
2.5
DISSOLVED FLUORIDE, IN MILLIGRAMS PER LITER
EXPLANATION
COLORS SHOW RANGE OF CONCENTRATION OF DISSOLVED FLUORIDE, IN MILLIGRAMS PER LITER
0.0-0.5
0.6-1.0
1.1-1.5
1.6-1.8
Colored dots represent stations monitoring flow from the Great Lakes
Water Resources Region Boundary
Accounting Unit Boundary
ALASKA
0 600 Miles
HAWAII
0 200 Miles
0 200 400 600 Miles
0 200 400 600 Kilometers
PUERTO RICO
0 100 Miles

Figure 92. Mean concentration of dissolved fluoride at NASQAN stations during 1975 water year. Recommended maxima shown on the histogram are from the National Academy of Sciences (149)

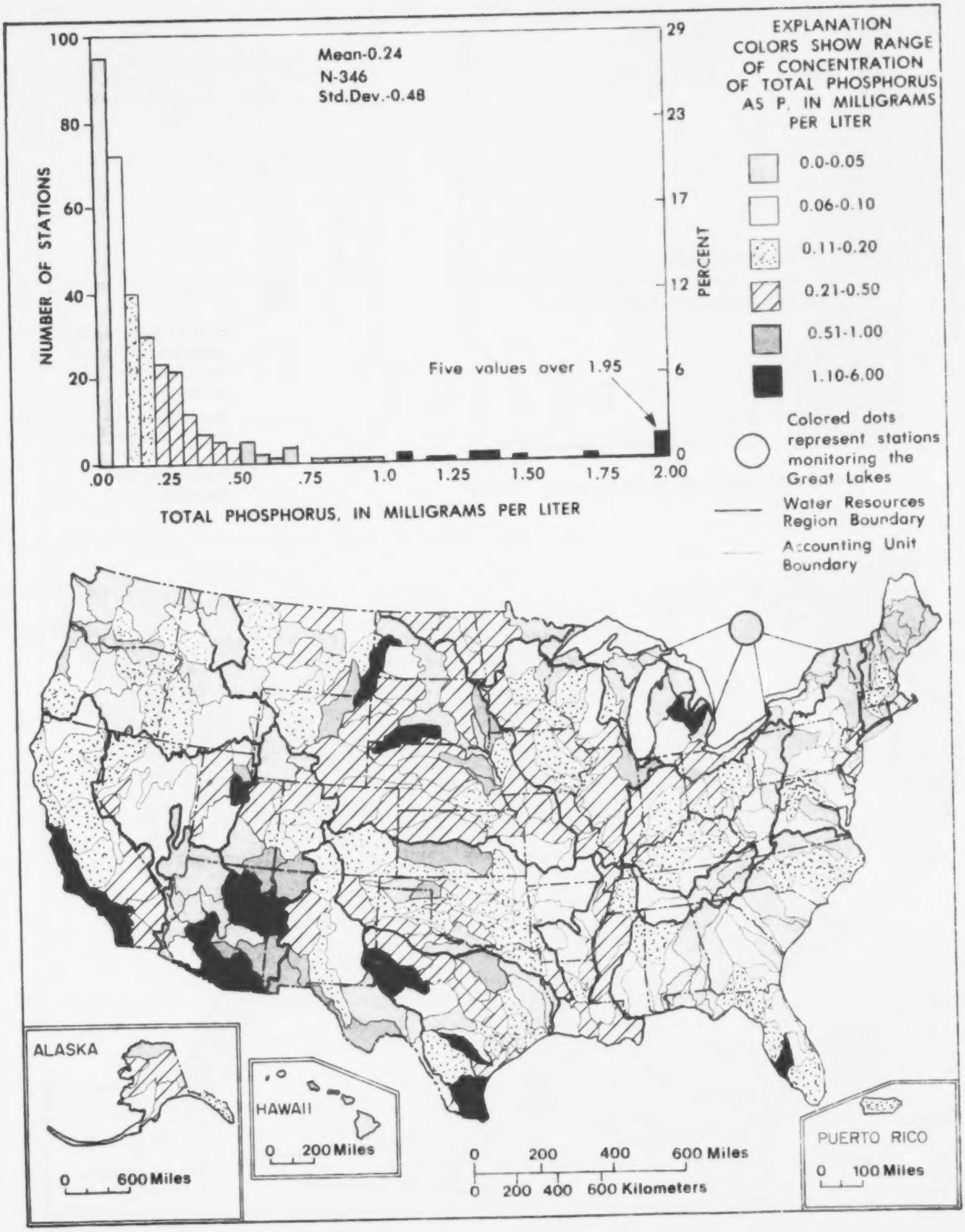

Mean-0.24
N-346
Std.Dev.-0.48
NUMBER OF STATIONS
100
80
60
40
20
0
PERCENT
29
23
17
12
6
0
Five values over 1.95
.00
.25
.50
.75
1.0
1.25
1.50
1.75
2.00
TOTAL PHOSPHORUS, IN MILLIGRAMS PER LITER
EXPLANATION
COLORS SHOW RANGE OF CONCENTRATION OF TOTAL PHOSPHORUS AS P, IN MILLIGRAMS PER LITER
0.0-0.05
0.06-0.10
0.11-0.20
0.21-0.50
0.51-1.00
1.10-6.00
Colored dots represent stations monitoring the Great Lakes
Water Resources Region Boundary
Accounting Unit Boundary
ALASKA
0 600 Miles
HAWAII
0 200 Miles
0 200 400 600 Miles
0 200 400 600 Kilometers
PUERTO RICO
0 100 Miles

Figure 93. Mean concentration of total phosphorus as P at NASQAN stations during 1975 water year (149)

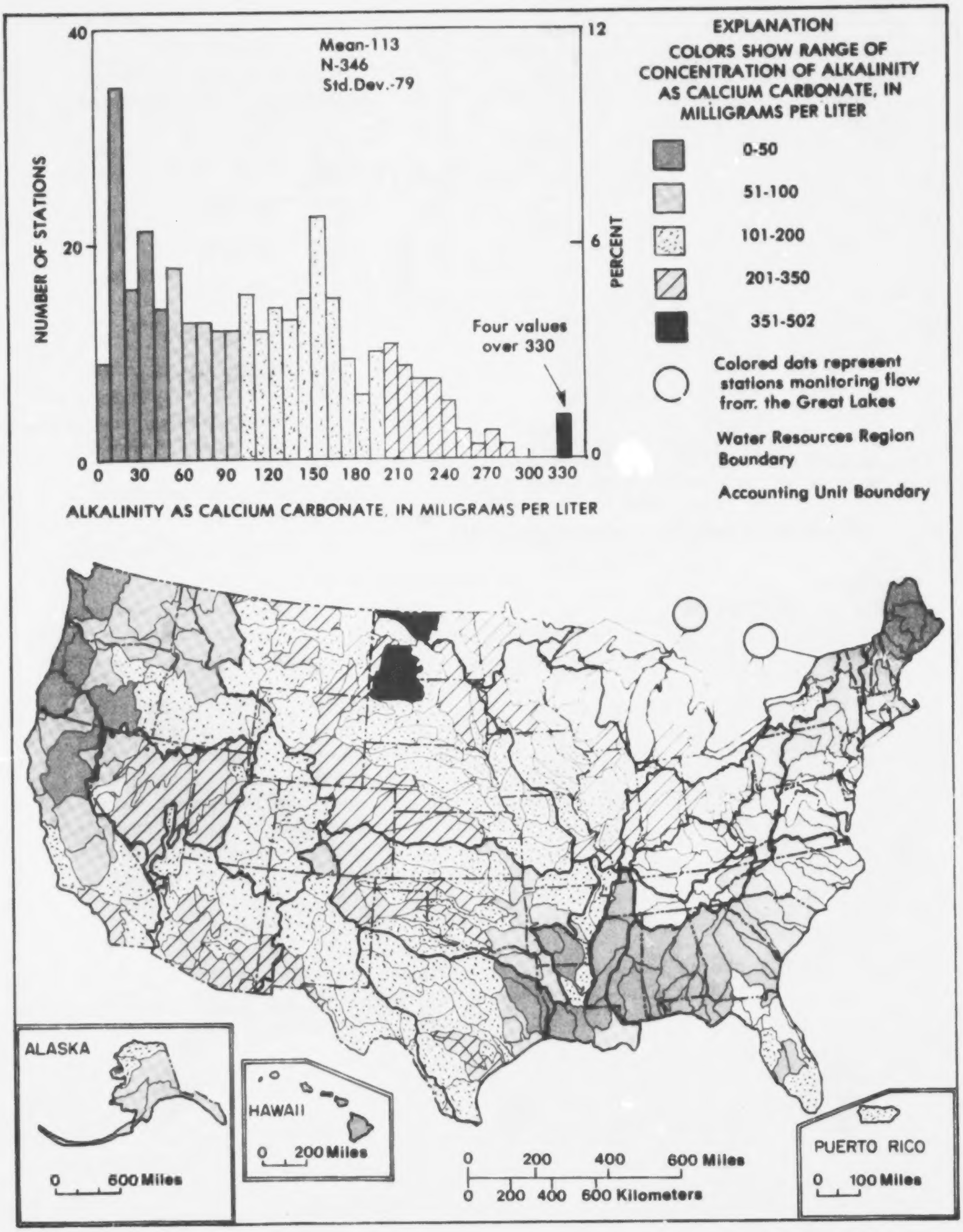

Mean-113
N-346
Std.Dev.-79
NUMBER OF STATIONS
PERCENT
40
20
0
12
6
0
Four values over 330
0 30 60 90 120 150 180 210 240 270 300 330
ALKALINITY AS CALCIUM CARBONATE, IN MILIGRAMS PER LITER
EXPLANATION
COLORS SHOW RANGE OF CONCENTRATION OF ALKALINITY AS CALCIUM CARBONATE, IN MILLIGRAMS PER LITER
0-50
51-100
101-200
201-350
351-502
Colored dots represent stations monitoring flow from the Great Lakes
Water Resources Region Boundary
Accounting Unit Boundary
ALASKA
0 600 Miles
HAWAII
0 200 Miles
0 200 400 600 Miles
0 200 400 600 Kilometers
PUERTO RICO
0 100 Miles

Figure 94. Mean alkalinity as calcium carbonate at NASQAN stations during 1975 water year (149)

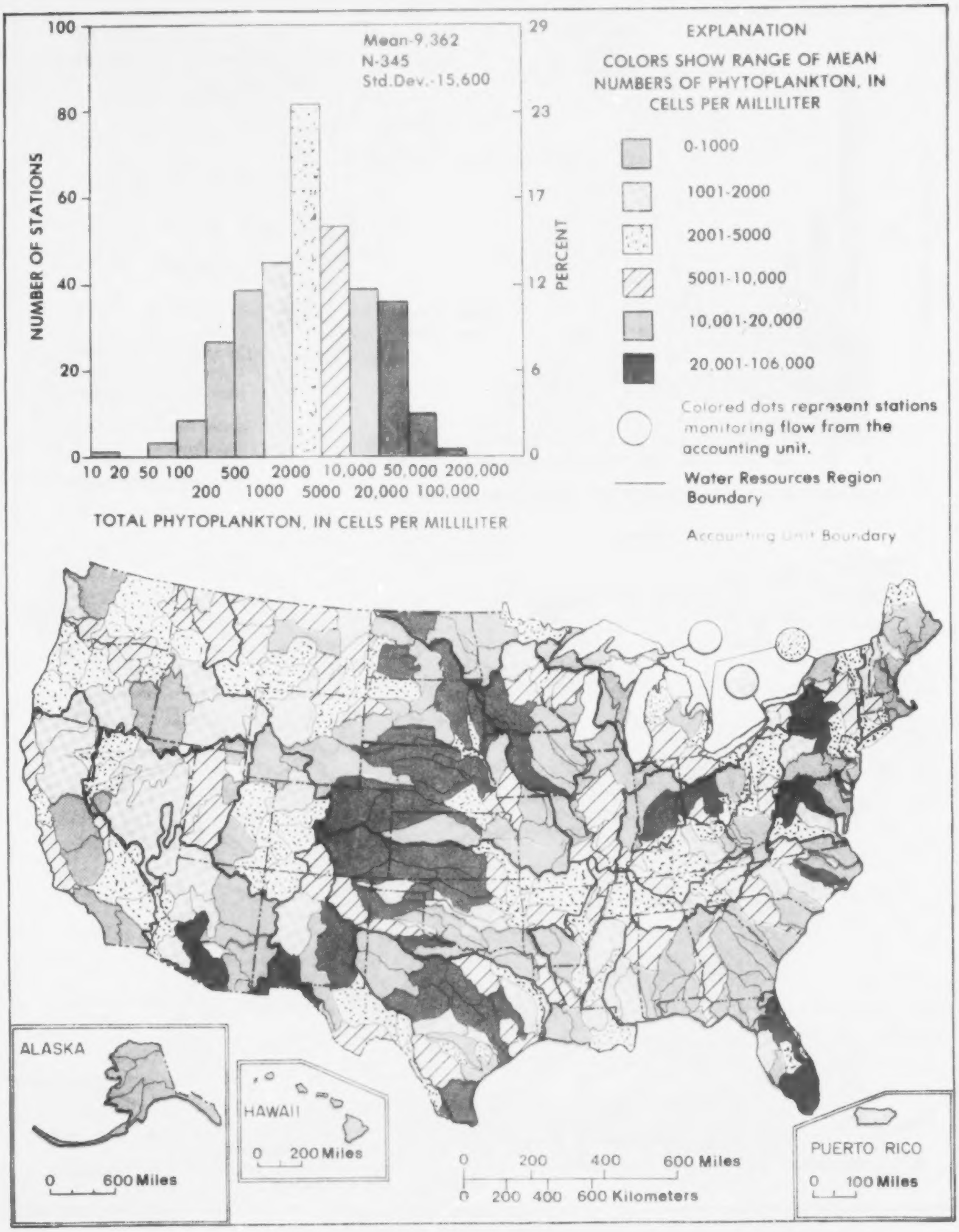

Mean-9,362
N-345
Std.Dev.-15,600
NUMBER OF STATIONS
100
80
60
40
20
0
29
23
17
12
6
0
PERCENT
10 20 50 100 500 2000 10,000 50,000 200,000
200 1000 5000 20,000 100,000
TOTAL PHYTOPLANKTON, IN CELLS PER MILLILITER
EXPLANATION
COLORS SHOW RANGE OF MEAN NUMBERS OF PHYTOPLANKTON, IN CELLS PER MILLILITER
0-1000
1001-2000
2001-5000
5001-10,000
10,001-20,000
20,001-106,000
Colored dots represent stations monitoring flow from the accounting unit.
Water Resources Region Boundary
Accounting Unit Boundary
ALASKA
0 600 Miles
HAWAII
0 200 Miles
0 200 400 600 Miles
0 200 400 600 Kilometers
PUERTO RICO
0 100 Miles

Figure 95. Mean numbers of phytoplankton sampled at NASQAN stations during 1975 water year (149)

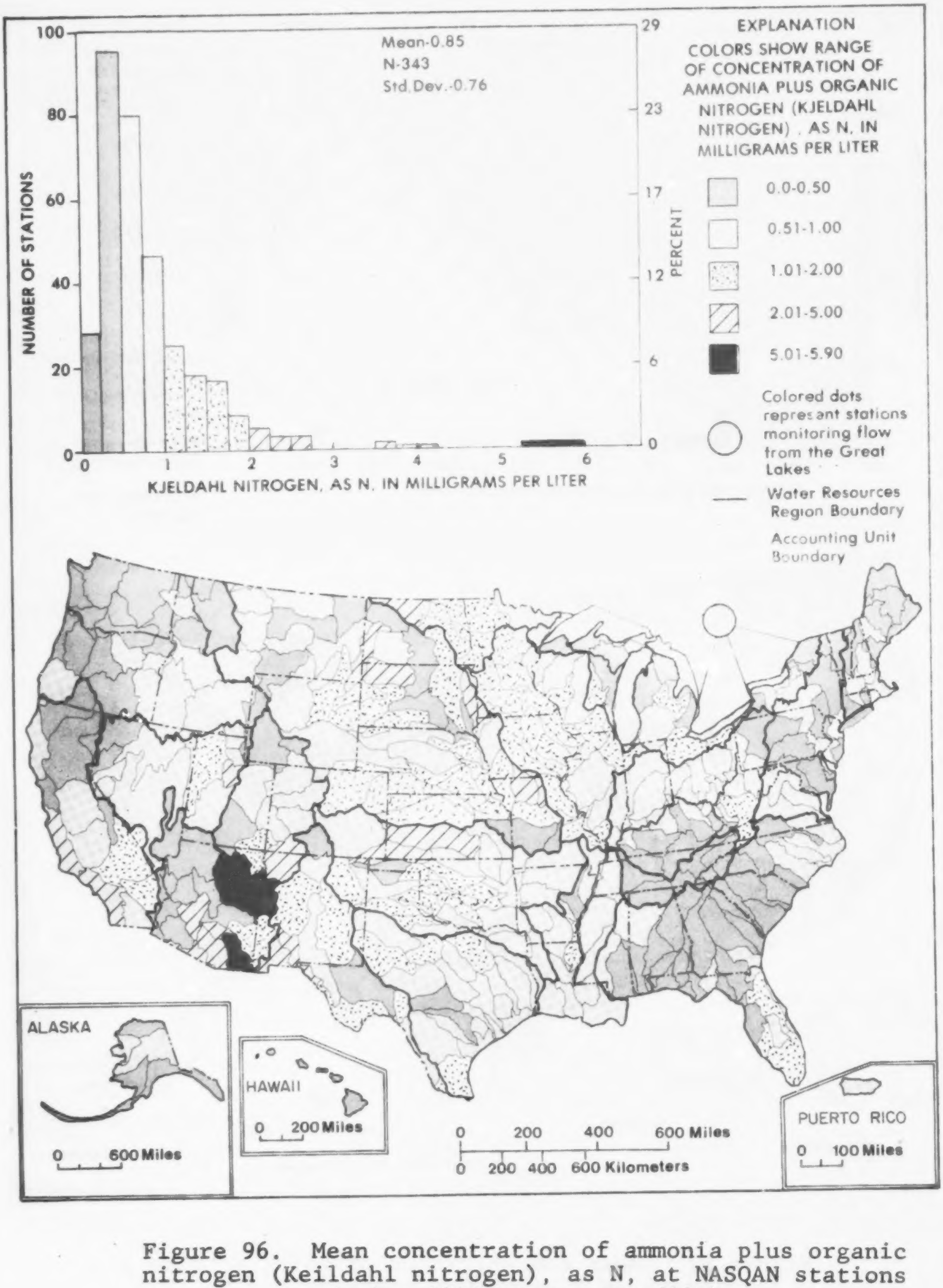

Mean-0.85
N-343
Std.Dev.-0.76
NUMBER OF STATIONS
100
80
60
40
20
0
PERCENT
29
23
17
12
6
0
0
1
2
3
4
5
6
KJELDAHL NITROGEN, AS N, IN MILLIGRAMS PER LITER
EXPLANATION
COLORS SHOW RANGE OF CONCENTRATION OF AMMONIA PLUS ORGANIC NITROGEN (KJELDAHL NITROGEN), AS N, IN MILLIGRAMS PER LITER
0.0-0.50
0.51-1.00
1.01-2.00
2.01-5.00
5.01-5.90
Colored dots represent stations monitoring flow from the Great Lakes
Water Resources Region Boundary
Accounting Unit Boundary
ALASKA
0 600 Miles
HAWAII
0 200 Miles
0 200 400 600 Miles
0 200 400 600 Kilometers
PUERTO RICO
0 100 Miles

Figure 96. Mean concentration of ammonia plus organic nitrogen (Keildahl nitrogen), as N, at NASQAN stations during 1975 water year (149)

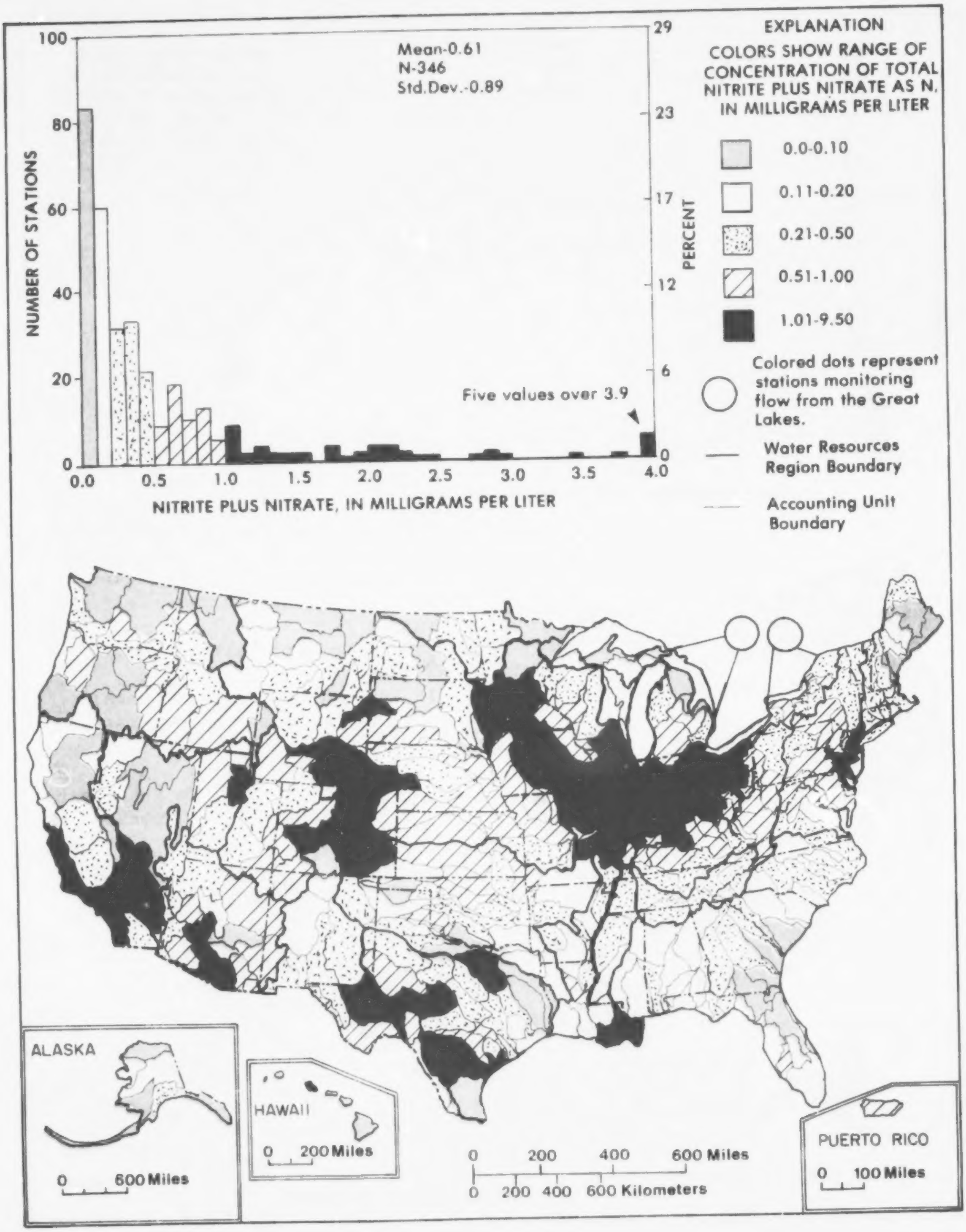

100
80
60
40
20
0
NUMBER OF STATIONS
Mean-0.61
N-346
Std.Dev.-0.89
29
23
17
12
6
0
PERCENT
Five values over 3.9
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
NITRITE PLUS NITRATE, IN MILLIGRAMS PER LITER
EXPLANATION
COLORS SHOW RANGE OF CONCENTRATION OF TOTAL NITRITE PLUS NITRATE AS N, IN MILLIGRAMS PER LITER
0.0-0.10
0.11-0.20
0.21-0.50
0.51-1.00
1.01-9.50
Colored dots represent stations monitoring flow from the Great Lakes.
Water Resources Region Boundary
Accounting Unit Boundary
ALASKA
0 600 Miles
HAWAII
0 200 Miles
0 200 400 600 Miles
0 200 400 600 Kilometers
PUERTO RICO
0 100 Miles

Figure 97. Mean concentration of total nitrite plus nitrate as N at NASQAN stations during 1975 water year (149)

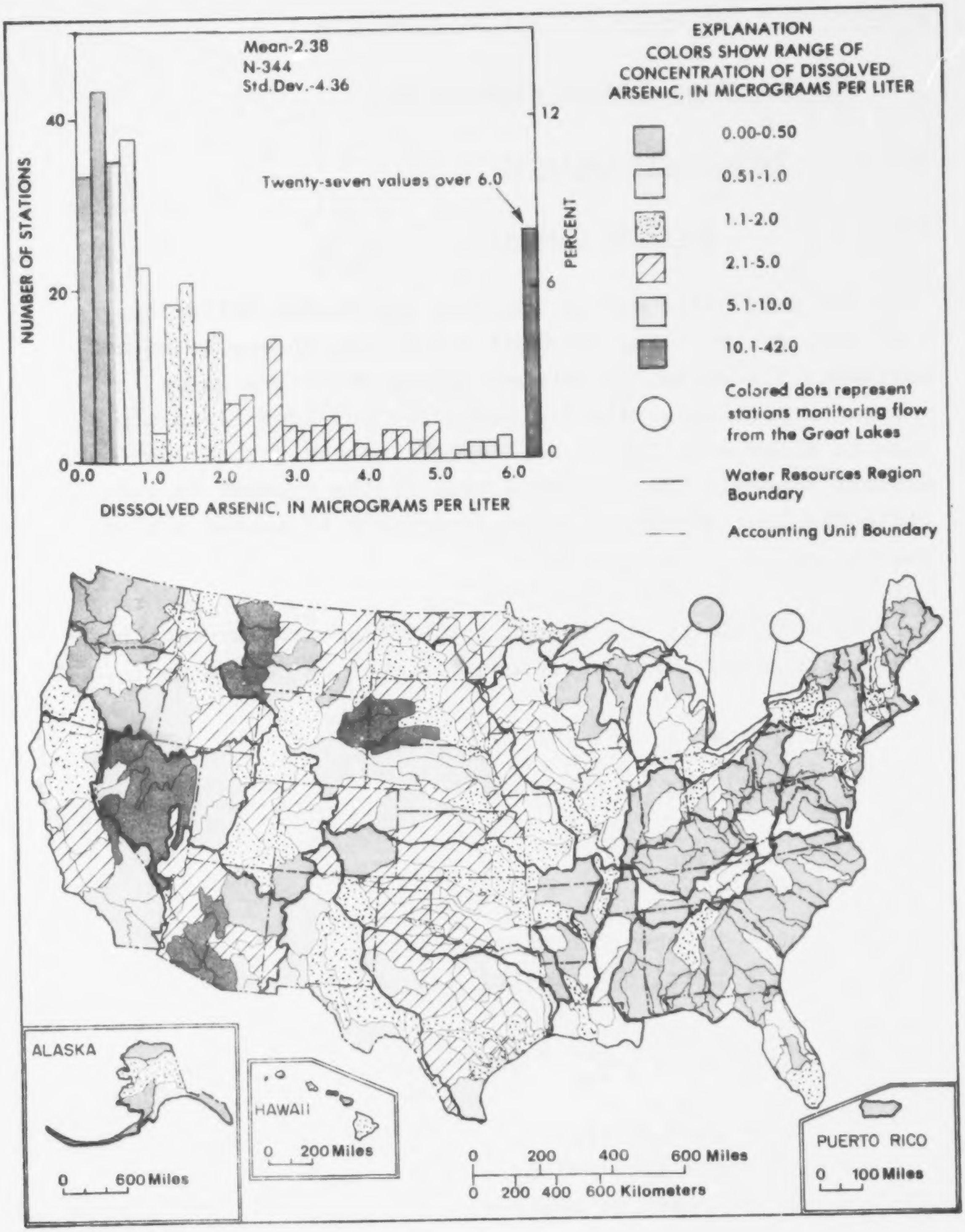

Mean-2.38
N-344
Std.Dev.-4.36
Twenty-seven values over 6.0
NUMBER OF STATIONS
PERCENT
0
20
40
0
6
12
0.0
1.0
2.0
3.0
4.0
5.0
6.0
DISSSOLVED ARSENIC, IN MICROGRAMS PER LITER
EXPLANATION
COLORS SHOW RANGE OF CONCENTRATION OF DISSOLVED ARSENIC, IN MICROGRAMS PER LITER
0.00-0.50
0.51-1.0
1.1-2.0
2.1-5.0
5.1-10.0
10.1-42.0
Colored dots represent stations monitoring flow from the Great Lakes
Water Resources Region Boundary
Accounting Unit Boundary
ALASKA
0 600 Miles
HAWAII
0 200 Miles
0 200 400 600 Miles
0 200 400 600 Kilometers
PUERTO RICO
0 100 Miles

Figure 98. Mean concentration of dissolved arsenic at NASQAN stations during 1975 water year (149)

APPENDIX D - Pollution Control Alternatives

D-1 Air Emissions Control Alternatives

D-1.1 Particulate Controls

D-1.1.1 Settling Chambers

The most basic of the inertial separation collectors available are settling chambers. Settling chambers are compartments placed in the exhaust stream which are large enough to provide a velocity reduction and long residence time to allow settling of particulate matter out of the exhaust stream. The residence time of the chamber is sufficiently long enough to allow a particle to settle out of the stream.

In determining the characteristics of gravity settling chambers the following relationships must be determined (6,8):

- $t_{settling} = t_{residence}$
- $t_{settling} = \frac{H}{V_s}$

  H = height of chamber
  V_s = settling velocity

- $t_{residence} = \frac{L}{V_g} = \frac{L}{Q/WH}$

  V_g = gas velocity
  Q = gas flow volume
  L = length of chamber
  W = width of chamber

- $V_s = \frac{(2r_p)^2 g\ (\rho_p - \rho_g)}{18\mu}$ (Stokes' Law)

where:
r_p = particle radius
g = acceleration due to gravity
μ = gas velocity
ρ_p, ρ_g = particle and gas density, respectively.

The minimum particle size which can be captured is:

$$r_{pmin} = \frac{1}{2}\left(\sqrt{\frac{18\mu H\ Vg}{gL(\rho_p - \rho_g)}}\right)$$

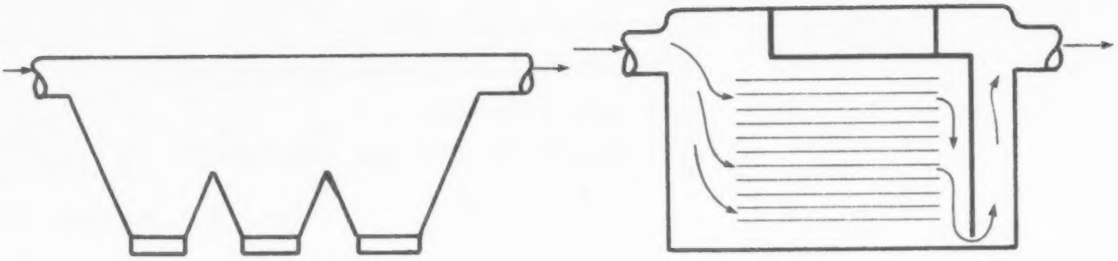
Collection efficiency is:

$$\eta = \frac{V_s\ WL}{Q} \times 100$$

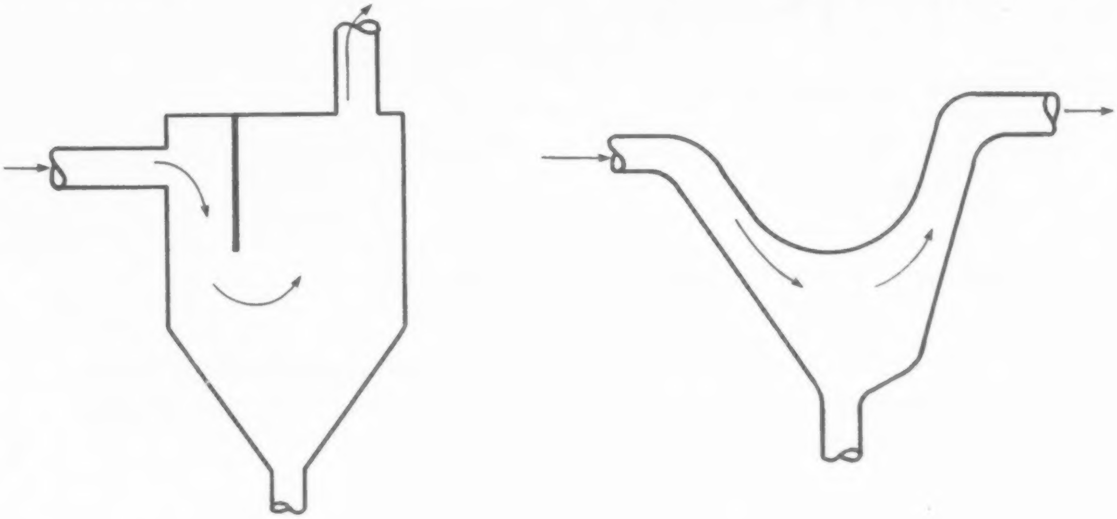
where: η = efficiency weight percent.

Figure 99 illustrates various configurations of simple settling chambers. The following list summarizes the advantages of settling chambers:

- Simple to construct
- Simple to maintain
- Economically capture particulate matter larger than 50 μm in size
- Operate at their greatest efficiencies at gas velocities less than 10 fps



a. Horizontal settling chamber b. Multi-tray settling chamber



c. Simple baffle chamber d. Rounded trap settling chamber

Figure 99. Settling chamber configurations

- They allow for a small internal duct pressure drop
- Mainly utilized as a pretreatment to remove large particulate matter prior to more efficient methods.

D-1.1.2 Cyclones (150,151,152)

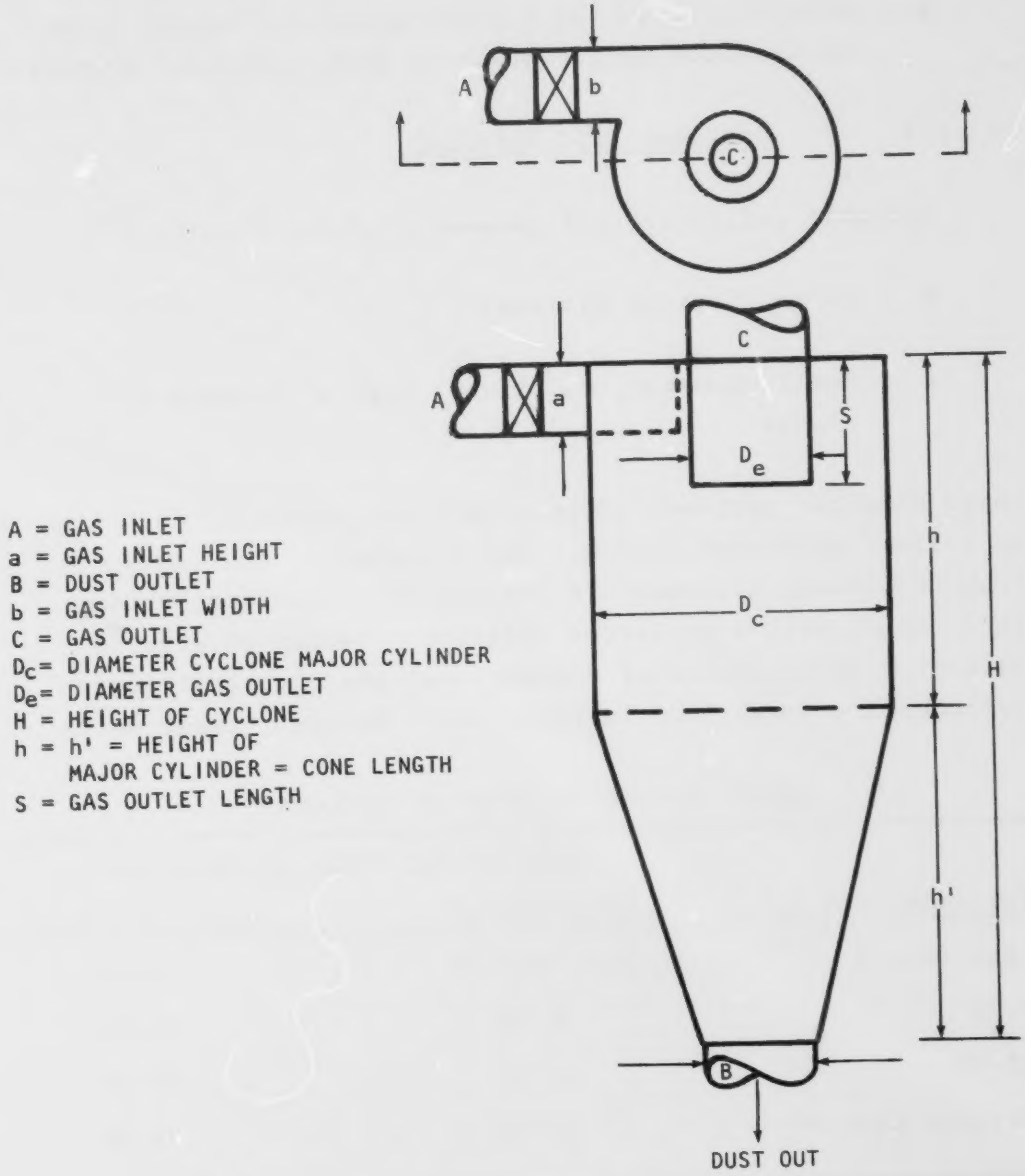
Cyclonic collectors are generally of two types:

- Large diameter cyclones
- Small diameter, multitube, high efficiency cyclones.

Large diameter cyclones (Figure 100) are primarily installed to collect particles >30 µm. Small diameter, multitube, high efficiency cyclones are capable of collecting particles >10 µm with a collector efficiency rating of over 90 percent. Efficiencies of conventional and high efficiency cyclones are summarized in Table 128. However, these units

TABLE 128. EFFICIENCY OF CYCLONES

	Efficiency Range (% Collected)	
Particle Size	Conventional	High Efficiency
Less than 5	Less than 50	50-80
5-20	50-80	80-95
15-40	80-95	95-99
Greater than 40	95-99	95-99



A = GAS INLET
a = GAS INLET HEIGHT
B = DUST OUTLET
b = GAS INLET WIDTH
C = GAS OUTLET
D_c= DIAMETER CYCLONE MAJOR CYLINDER
D_e= DIAMETER GAS OUTLET
H = HEIGHT OF CYCLONE
h = h' = HEIGHT OF
MAJOR CYLINDER = CONE LENGTH
S = GAS OUTLET LENGTH

Figure 100. Conventional cyclone separator

are expensive to install and usually require more maintenance than large diameter cyclones. The principle behind cyclone collection is that centrifugal forces on particulate matter in a spinning gas stream may be many times in excess of gravitational forces. Therefore, particulate matter tends to collect on the walls of the cyclone. The downwind spiraling effect of the gas stream forces the particulate matter to the bottom of the cyclone where they are collected.

Cyclone design characteristics are as follows:

Major cylinder height	$h = 2 D_c$
Cone length	$h = 2 D_c$
Gas outlet diameter	$D_e = .5 D_c$
Gas outlet length	$H+S - .625 D_c$
Gas inlet height	$a = .5 D_c$
Gas inlet width	$b = .25 D_c$
Dust outlet	$B = .25 D_c$

Cyclone efficiency increases with an increase in the following:

- Density of the particulate matter
- Inlet velocity to cyclone
- Cyclone body length
- Number of revolutions made by gas streams in cyclone body
- Ratio of cyclone body diameter to cyclone outlet diameter
- Particle diameter

- Particulate volume entrained in carrier gas
- Smoothness of interior cyclone body.

A theoretical approach to predict cyclone efficiency has been advanced by Leith and Licht (152) based on the concept of continual radial back mixing of uncontrolled particles, coupled with the calculations of an average residence time for the gas in a cyclone. Leith and Licht stated that cyclone efficiency may be calculated by:

- $E = 1 - \exp - 2 \frac{G\ s\ Q}{D_c^3} (N+1)^{(0.5/(N+1)}$

where: E = cyclone efficiency (%)
G = cyclone configuration factor
s = residence time
Q = volumetric gas flow rate
N = Vortex exponent

- $s = P_p (D_p)^2 / \left(18(u)\right)$

where: P_p = particle density
D_p = particle diameter intercepted
u = fluid viscosity

- $G = 8(K_c)/(k_a)^2 (k_b)^2$

where: k_c = volume of cyclone cylinder
$k_a = a/D_c$
$k_b = b/D_c$

- $\eta = 1 - \left[1 - \left(\frac{12\ D_c^{\ 0.14}}{2.5} \times \frac{T + 460^{0.3}}{530}\right)\right]$

where: T = temperature, °F

the overall efficiency for a cyclone can then be calculated as follows:

$$\eta_T = m_i \eta_i$$

where: η_T = overall efficiency

m_i = mass fraction of particles in size range i

η_i = efficiency of cyclone at midpoint of interval i, %

A correct estimate of the pressure drop across a cyclone is necessary, in addition to cyclone efficiency, so that cost effectiveness may be calculated. A pressure drop magnitude of 10 or less in H_2O is generally accepted operating range. The following equations determine the pressure drop across a cyclone separator (153):

- $F = \frac{K\ a\ b}{D_e^2}$

where: K = dimensionless constant

- $D_c = \frac{2.34}{K^{0.272}}$

When collection of particulate matter in the 5 to 10 micron range is required, multiple small diameter cyclones are utilized. Multiple cyclone separators consist of a number of long small diameter cyclones operating in parallel, having a common gas inlet and outlet. Gas flow is substantially different in the multiple cyclone separators in that gas enters the top of the cyclone and is passed by a stationary vane which imparts the spinning motion to the gas flow. These cyclone separators are high in efficiency, but are expensive to operate and increase the pressure drop across the cyclone. Multiple cyclone separators efficiency is determined by the same procedure as for large diameter cyclones.

D-1.1.3 Electrostatic Precipitators

Electrostatic precipitators operate by using a direct current voltage to create an electric field between a negatively charged discharge electrode and a posititively charged collection electrode. As the suspended particles (or aerosols) pass between the electrodes the particles are charged and collected on the oppositely charged electrode. The deposited matter is removed by rapping or washing the electrode. The precipitated material is then collected in hoppers for final disposal.

Electrostatic precipitators exhibit removal efficiencies of 90 to 99 percent within a particle range of less than 0.1 microns to 200 microns (154). Precipitators have the ability to handle very large flow rates at high efficiencies. They can operate in a wide range of temperatures and pressures, up to 800°C and 50 atmospheres, respectively (155). Their major disadvantages include high initial cost and little adaptability to changing process conditions.

Removal efficiency is directly related to the volumetric gas flow rate, as described by the following equation (154):

$$F = 1 - e^{\frac{(-WA)}{Q}}$$

where: F = efficiency
A = collecting area
Q = volumetric flow rate
W = drift velocity

The drift velocity, W, can be calculated by the following equation (154):

$$W = \left(1 + 1.72 \frac{L}{D_p}\right) \frac{D_p E_o E_p}{4\pi\mu}$$

where: W = drift velocity

D_p = particle diameter

L = mean free path of gas

E_p = precipitation field density

E_o = corona field strength

μ = absolute viscosity of the gas

Removal efficiencies are dependent on the temperature and humidity of the gas stream. An increase in humidity and/or a decrease in temperature will cause a decrease in sparkover voltage, i.e., the voltage at which the gas becomes locally conductive. At sparkover voltage there is a dramatic decrease in the electric field strength and hence a large power loss. Such gas streams as dryer off-gases may be too humid to separate particulates by electrostatic precipitation.

D-1.1.4 Filtration

Baghouses and fabric filters are used for high efficiency removal (up to 99.9%) of particulates from gases. Baghouses and fabric filters, along with dry collectors, share the following characteristics.

- Particulates are collected dry and in usable condition.
- Gases are not cooled or saturated with moisture.
- Solids handling accessories must be properly designed to avoid secondary dust generation.
- Unlike scrubbers, filters do not add moisture to the cleaned exhaust and do not create a plume.
- There is an explosion hazard risk; proper fire protection equipment must be on-site.

There are two major types of bag filters. Envelope-type bags prove maximum surface area per unit volume, but suffer from dust bridging problems and are difficult to change. Tubular bags are open at one end and closed at the other, with the direction of filtering being either inside-out or outside-in. An outside-in design requires a frame to prevent bag collapse and has a shorter bag life. Tubular filter bags are often sewn together to form multibag systems; the major disadvantage is costly bag replacement.

Different gas characteristics require different filter media for proper operation. There are three main filter types: paper filters, woven fabric filters, and felted fabric filters. Paper filters are used for sampling and analysis and clean room use rather than in large industrial units. Woven fabric filters are employed with low air/cloth ratios, generally from 7.6×10^{-3} to 3.0×10^{2} $m^3/s/m^2$ (1). Fabric life is a function of operation temperature, frequency and method of cleaning, and properties of particulates and carrier gas. Average life of woven fabric filters ranges from 6 to 18 months. Performance of some filter fabrics are summarized in Table 130 (154). The more efficient felted fabrics are more expensive, but can be utilized with high air/cloth ratios typically 6.1×10^{-2} $m^3/s/m^2$ (154). Felted fabrics require thorough cleaning for proper operation.

Cleaning methods affect air/cloth ratios significantly. Cleaning by shaking can be accomplished manually or mechanically, intermittently or continuously. Reverse jet cleaning uses compressed air to remove filter cake from the fabric. Reverse air flexing is accomplished by reversing gas flow to cause a filter backwash effect.

Air-to-cloth ratios for coal dust are shown for different types of cleaning mechanisms in Table 129.

TABLE 129. AIR-TO-CLOTH RATIOS FOR COAL DUST

Type of Cleaning	Air/Cloth Ratio, $m^3/s/m^2 \times 10^{-2}$
Shaker	1.3 - 1.5
Reverse Jet	5.1 6.1
Reverse Air Flexing	0.6 1.0

TABLE 130. CHARACTERISTICS OF FILTER FABRICS (154)

		Physical Resistance					Chemical Resistance				
Fabric	Specific Gravity	Dry Heat	Moist Heat	Abrasion	Shaking	Flexing	Acids	Acids	Alkalies	Oxidizing Agents	Solvents
Cotton	1.6	G	G	F	G	G	P	G	F	F	E
Dacron	1.4	G	F	G	E	E	G	G	F	G	E
Orlon	1.2	G	G	G	G	E	G	G	F	G	E
Mylon	1.1	G	G	E	E	E	P	F	G	F	E
Dynel	1.3	F	F	F	P-F	G	G	G	G	G	G
Polypropylene	0.9	G	F	E	E	G	E	E	E	G	G
Creslan	1.2	G	G	G	G	E	G	G	F	G	E
Vycron	1.4	G	F	G	E	E	G	G	G	G	E
Nomex	1.4	E	E	E	E	E	P-F	E	G	G	E
Teflon	2.3	E	E	P-F	G	G	E	E	E	E	E
Wool	1.3	F	F	G	F	G	F	F	P	P	E
Glass	2.5	E	E	P	P	F	E	E	G	E	E

E = Excellent
G = Good
F = Fair
P = Poor

D-1.1.5 Wet Scrubbers

Wet scrubbers comprise a large variety of equipment, the main types being spray chambers, impingement plate scrubbers, venturi scrubbers, cyclone-type scrubbers, orifice-type scrubbers, and packed bed scrubbers. Low pressure scrubbers, such as spray towers collect coarse dusts in the range of 2 to 5 microns. High pressure drop venturi scrubbers are effective at removing 0.1 to 1.0 micron particles at up to 98 percent efficiency (155).

The wet scrubbers remove dust from the carrier gas stream by contacting it with water or a specified scrubbing liquor. The following is a list of the characteristics of wet scrubber technologies (154).

- The flue gas is both cleaned and cooled.
- Stack effluent will contain fines, mists, and steam plume.
- The temperature and moisture content of the inlet gas is essentially unlimited.
- Corrosive gases can be neutralized with proper scrubbing liquor selection.
- Consideration of freezing conditions is important.
- Hazards of explosion are reduced.
- Equipment is relatively compact and capital cost is less than dry collection equipment.

- The equipment is highly efficient in collecting a wide range of particulate sizes.
- Removes simultaneously gaseous pollutants such as sulfur dioxide, hydrogen sulfide, and nitrogen oxides.
- Maintenance cost is lower because of simple design.
- Water utilization is high and is an important consideration in certain areas.

Efficiencies of various scrubbers at different particle sizes are shown in Table 131. Wet scrubbers that can be applied to coal dusts and fly ash control are shown in Table 132.

TABLE 131. EFFICIENCY OF SCRUBBERS AT VARIOUS PARTICLE SIZES (154)

Type of Scrubber	Percentage Efficiency at 50μ	5μ	1μ
Jet-impingement scrubber	98	83	40
Irrigated cyclone	100	87	42
Self-induced spray scrubber	100	94	48
Spray tower	99	94	55
Fluid bed scrubber	99+	98	58
Irrigated target scrubber	100	97	50
Disintegrator	100	98	91
Low energy venturi scrubber	100	99+	96
Medium energy venturi scrubber	100	99+	97
High energy venturi scrubber	100	99+	98

TABLE 132. APPLICABILITY OF VARIOUS WET SCRUBBERS TO COAL DUSTS AND FLY ASH (154)

Type of Scrubber	Coal Dust	Fly Ash	Collection Efficiency (%)
Elbair scrubber	X	X	99+, 99
Floating bed		X	N.A.
Flooded bed		X	N.A.
Cyclonic		X	96+
Self-induced spray scrubbers	X		N.A.
Mechanically induced spray	X		N.A.
Venturi scrubbers	X	X	96, 99+

N.A. = Not Available

D-1.2 Hydrocarbon Controls

Four types of control technologies that can be employed to treat gas streams containing hydrocarbons are: (1) direct-fired and catalytic afterburners, (2) condensation systems, (3) adsorption systems and (4) flares.

Direct-fired and catalytic afterburners employ high temperatures to carry out oxidation of organics to carbon dioxide and water. They are applicable to gases with hydrocarbon content below the limit of flammability. In general, catalytic afterburners, with platinum or palladium catalysts to facilitate oxidation, utilize temperatures lower than the direct-fired afterburners. A comparison of temperatures required to convert various combustibles to carbon dioxide and water for both direct-fired and catalytic afterburners is given in Table 133.

TABLE 133. COMBUSTION TEMPERATURES IN DIRECT-FIRED AND CATALYTIC AFTERBURNERS (154)

Combustible	Ignition Temperature (°C) Direct-Fired	Catalytic
Methane	632	500
Carbon Monoxide	665	260
Hydrogen	574	121
Propane	480	260
Benzene	580	302

Direct-fired afterburners have exhibited conversion efficiencies of more than 99 percent while catalytic units have slightly lower efficiencies (85 to 92 percent) (155).

Direct-fired afterburners are designed to operate at about 760°C with retention times of at least 0.8 seconds (155). Catalytic afterburners operate at about 538°C with retention times of 0.05 to 0.1 seconds (155). Operating temperatures are sustained by combustion of a fuel gas. This fuel consumption can only be partially offset by heat recovery systems in which heat from exhaust gases is used to preheat incoming gases. Another general disadvantage of afterburners is that they produce no saleable product.

Catalytic afterburners have a number of important advantages and disadvantages compared to direct-fired units. Because they operate at lower temperatures, they have lower operating and maintenance costs. Initial capital equipment cost, however, is higher. Catalysts also are easily poisoned by heavy metals, halogens, and sulfur compounds, or fouled by inorganic particulates. Catalytic incineration devices have been judged by the Los Angeles County Air Pollution Control District to be incapable of meeting efficiency requirements of 90 percent conversion.

In condensation systems, the gas stream is cooled and compressed to facilitate condensation of vapor phase pollutants. Condensation is applicable when pollutants with dewpoints above 30°C are present in high concentrations. Condensers are normally used in conjunction with other control equipment, since they are a relatively inefficient means of control at lower organic concentrations.

Carbon adsorption systems employ parallel cycling beds of activated carbon to adsorb gaseous organic pollutants. Removal efficiencies are claimed to be up to 95 percent (154). Carbon bed regeneration and desorption of organics is accomplished by a number of means, i.e., steam contacting, hot inert gas contacting, or vacuum desorption. The concentrated organic vapor is either incinerated or recovered as solvent by condensation, distillation, or adsorption.

The major advantages of carbon adsorption systems are that a saleable organic solvent may be recovered through desorption, or the desorbed concentrated gaseous pollutant can be incinerated in a much smaller unit with much less fuel consumption than if the original gas stream were incincerated. Another major advantage of carbon adsorption is that sulfur oxides, nitrogen oxides, and carbon monoxide are concurrently adsorbed with organic vapors.

There are a number of important design criteria that must be considered when selecting carbon adsorption systems (154). If pollutant concentration is below 0.1 percent by volume, carbon regeneration is not economical and a nonregenerative system should be utilized, in which spent carbon would be disposed of or regenerated in external equipment. The capacity of the solid adsorbent decreases with increasing temperature; therefore operating temperatures should be kept below 40°C for efficient operation. Because the adsorption reaction is exothermic, there is a temperature rise of about 10C° for dilute organic solvent-air mixtures. However, concentrated hydrocarbon streams can cause temperatures to rise to dangerously high levels, presenting an explosion hazard if the gas-air mixture is within explosive limits. Excessive temperature fluctuations must be avoided since periods of temperature rise can cause massive desorption (154).

Operational problems are mainly related to the adsorbent surface. High molecular weight molecules may not be easily desorbed under normal regeneration; high temperature steam stripping may be required to control organic build-up. Particulate matter may adhere to the adsorbent surface and become alsmost impossible to remove. Plugging may occur from particulate build-up. In some operations it may be necessary to place a filter at the inlet to the adsorber to protect against particulate entry. Corrosion can be a problem if steam stripping is used for adsorbent regeneration. Light hydrocarbons, such as methane and ethane, are not effectively adsorbed and will be present in the off-gas (154).

Flares incorporate direct combustion of the pollutant gases with air, and can be used only if the organic concentration of the gas stream is in the flammable range. Flaring is the least costly form of incineration since the fuel is usually made available to maintain a flammable mixture in the event the organic concentration drops below the lower explosive limit.

The hydrocarbon-rich pressure control releases from SRC systems are considered suitable for disposal by flaring. There are three basic classifications of combustion flares, as follows:

- Elevated combustion flares
- Ground combustion flares
- Ground pits

Burning pits are generally unacceptable except as a device to handle catastrophic emergency situations. They are excavated units with alloy steel burners along one or more sides. The walls are usually concrete or refractory-lined. Dense clouds of smoke are released during operation and the combustion products are not dispersed efficiently. Elevated and ground combustion flares are discussed below. ELevated combustion flares are the most commonly used type. The combustion tip is usually 33-100 meters above grade, which drastically reduces the effects of heat radiation. Consequently, the flare can be located close to process units. In this way, the amount of vent piping and land requirements are minimized. The extra height also gives the added advantage of better dispersion of combustion products than with ground flares. Minimum height is determined with respect to radiation protection and is adjusted upward so that ground level contaminant concentrations will meet ambient air standards. The elevated flares, depending upon the method of achieving smokeless combustion, utilize air inspiration with steam or mechanical air blowing.

Steam injection into the flare tip can greatly reduce or even eliminate smoke generation. This reduction results from two effects. Steam has an inspirating effect and drass large quantities of air into the combustion zone. This supplies necessary oxygen for burning, provides intense mixing, and has a solvent cooling effect which reduces cracking and polymerization. The steam also reacts with untreated carbon particles to form carbon monoxide and hydrogen.

The principal methods for injecting steam into flares involve the use of multiple jets, single nozzles, or a shroud. In the multiple jet design, waste gases are exhausted from the open end of the flare tip. A large header located around the periphery of the tip distributes steam to several jets. The jets are oriented so that their discharge covers the tip and creates turbulence and mixing of the waste gases with the surrounding air. Steam consumption is relatively low, 0.1-0.2 kg of steam per kilogram of waste gas; however, this is balanced against the maintenance costs which are slightly higher than the single nozzle design. Tip construction utilizes corrosion-resistant alloy steel (154).

In single steam nozzle design, the steam line enters the flare and continues upward in the center until it terminates several inches below the top of the tip. As the steam exits the supply line, it expands to fill the inside of the flare tip and, in so doing, mixes with the waste gas. The turbulence created is not as great as with multiple jets. However, the system requires less maintenance due to its simple design (154).

In the shroud type design, the flare tip is surrounded by a metal skirt or shroud. This reduces some of the cross-wind effects and forms a turbulent zone for premixing of the air and steam. Waste gas exits radially from the center portion of the tip and travels toward the shroud, causing intense mixing with the vent gas. Steam utilization is comparable with that of the multiple steam jet type. (154).

In mechanical air blowing, blowers are utilized to provide air for smokeless combustion of small gas streams. For gas rates over 45.4 Mg-moles/hr, the amount of air requires large equipment. Capital investment is not competitive with steam injection systems, if steam is available.

Ground flares are built near grade level and seldom exceed 20 meters in height. Consequently, heat radiation effects require that flares be limited in size and located away from the process areas. This raises piping costs and eliminates them from consideration in plants with little available space and high-vent gas rates. Greatest application is for locations where elevated flares would be unsightly and complete smokeless operation is not required (154).

Ground flares have an important advantage in that water can be substituted for steam in many cases. Consequently, operating costs are greatly reduced. However, as the water requirement increases at high vent gas rates, it becomes increasingly difficult to obtain satisfactory combustion. Therefore, smokeless operation is limited to a maximum of 45.4 Mg-moles/hr gas flowrate (154).

A typical water injected ground flare is composed of three concentric stacks. The innermost stack contains the burner and water atomization nozzles. The second stack is slightly larger and serves to confine the tiny water droplets for effective mixing with the incoming air and the vent gases. The outermost stack merely directs the flame upward and protects against crosswinds. Slots are provided near the base of all three stacks to allow entrance of air by natural draft (154).

Ground flares can be designed to handle higher vent gas rates by using air inspirating venturi burners. Application is limited due to a pressure requirement 7,000-28,000 Pa at the burner and 48,000 Pa backpressure (154).

Several burners are required to handle a wide range of vent gas rates. These auxiliary burners and their automatic control valves become a significant cost item. A major drawback of the system is that it cannot handle vent rates which substantially differ from the design basis.

D-1.3 Sulfur Dioxide Controls

There are well over thirty processes that have been developed for the control of sulfur dioxide stack emissions. They can be divided into a number of broad categories, namely dry additive injection (limestone), dry adsorptive processes, wet adsorption processes, adsorption by charcoal, and catalytic conversion processes.

The dry additive injection process involves the introduction of pulverized limestone or dolomite directly into the flue gas. The additive reacts with sulfur dioxide and oxygen in the flue gas to form calcium or magnesium sulfate. Major characteristics of dry additive injection techniques are listed below (154):

- Flyash and limestone particles are carried along in the gas stream and must be removed by another pollution control unit.
- Capital cost is low. Feed materials are relatively inexpensive.

- SO_2 removal efficiencies are low.

- Operational difficulties included sintering and slagging of limestone.

- There is little corrosion and no interference with boiler operation.

- It is a throw-away process and presents solid waste disposal problems.

Dry adsorption processes utilize a bed of metal oxide to adsorb sulfur dioxide from the gas stream. The metal oxide is converted to the sulfated form and must be regenerated. A list of characteristics of dry adsorption techniques is given below:

- Adsorbent generation is difficult and the adsorbents lose their activity after a number of regeneration cycles.

- The most effective adsorbents are very expensive.

- Fly ash and metal oxide particulates must be removed in a second pollution control unit.

- Little corrosion of metal surfaces occurs, and in most cases there is no pressure loss through the system.

- A saleable by-product such as ammonium sulfate can be produced; hydrogen sulfide, which can be routed to the Stretford unit for recovery of sulfur, may be produced.

- Particulate matter may plug absorbent beds.

Wet adsorption processes employ a spray tower or other wet scrubber to carry out sulfur dioxide removal. The adsorbent liquid is usually a water solution of lime, dolomite, metal sulfite, magnesium and manganese oxides, ammonia, or caustic soda. Products from regeneration are concentrated sulfur dioxide, ammonium sulfate, or a waste stream. A number of characteristics in the processes are listed below (154):

- Wet adsorption methods are not restricted by temperatures or residence times within the furnace.
- They can be added to existing units without boiler modifications.
- Heat loss due to scrubbing reduces plume buoyancy and the effluent gas stream must be reheated.
- Adsorbents have a capacity for heavy loading but require complex regeneration unless a throw-away system is acceptable.
- Wet adsorption techniques remove particulates and nitrogen oxides as well as sulfur oxides.
- Mist eliminators must be included to avoid excess plume opacity.
- Efficiencies in most wet absorption processes are better than 90 percent.

Charcoal adsorption systems utilize commercial activated carbon to chemisorb sulfur dioxide from the gas stream. The sulfur dioxide is oxidized to sulfuric acid in the presence of water vapor and oxygen. The spent carbon is regenerated thermally. Both dry and wet adsorption technologies are available. Advantages and disadvantages of charcoal adsorption systems are listed below:

- Smaller adsorber-desorber units are required due to the short retention periods.
- Problems with regeneration are inherent including loss of carbon due to carbon monoxide and carbon dioxide formation during thermal regeneration.
- Wet processes require added equipment and corrosion resistant construction.
- Due to the continuous movement of the charcoal material in the system, carbon abrasion becomes a problem.
- Wet processes generate a wastewater stream and reduce plume buoyancy.

In catalytic conversion processes, gaseous sulfur dioxide is oxidized to sulfur trioxide in the presence of a vanadium catalyst. The sulfur trioxide reacts with water vapor in the flue gas and is condensed as sulfuric acid. The characteristics of catalytic conversion of sulfur dioxide are discussed below (154):

- It is a simple process with no catalyst recycling required. There is no heat loss and plume buoyancy is maintained.

- Corrosion resistant materials are required.

- A particulate control unit is required to remove fly ash so that reactor plugging does not occur.

- The gas stream must be reheated to a high temperature for efficient conversion (371 to 472°C).

- A mist eliminator or electrostatic precipitator must be added at the end of the process.

- A saleable by-product (sulfuric acid or ammonium sulfate) is produced.

Because of the large number of sulfur dioxide removal processes, it is not possible to discuss each one separately. A summary of known removal processes is given in Table 134.

D-1.4 Secondary Sulfur Recovery Processes

D-1.4.1 Beavon Process

In the Beavon process, entering tail gas from primary sulfur recovery is mixed with hot flue gas. The gas is passed through a catalytic reactor containing a cobalt-molybdate catalyst. Sulfur compounds are hydrogenated to form hydrogen sulfide. The gas is then cooled. Water vapor condenses, leaving a cool, dry gas. The gas is then passed

TABLE 134. SULFUR DIOXIDE CONTROL ALTERNATIVES (156)

PROCESS	SORPTION		REGENERATION		SPONSORING ORGANIZATIONS
	SORBENT	PRODUCTS	RAW MATERIAL	PRODUCTS	
		Low Temperature Aqueous Sorption and Regeneration			
Sea water	H_2O	H_2SO_3, sulfites	CaO, Mn^{++}	$CaSO_4$	Battersea, Haenisch-Schroeder, Karagama
Sulfacid	H_2O, charcoal	H_2SO_3, H_2SO_4	–	Dilute H_2SO_4	Lurgi, Hitachi
Westvaco	"	"	H_2S	S, SO_2	Westvaco
Thiogen	H_2O	H_2SO_3	BaS	S, SO_4^{-2}, $S_2O_4^{-2}$	Balakalla smelter
Ozone	H_2O,O_3,$MnSO_4$	H_2SO_4	–	–	TVA
Soda	Na_2CO_3	Na_2SO_3 Na_2SO_4	–	–	UOP, Wisconsin Power, Peabody Coal, Dow Chemical, Nevada Power
Soda-ZnO	NaOH,Na_2SO_3	$NaHSO_3$	ZnO	$ZnSO_4$,$ZnSO_3$, ZnO,Na_2SO_3, SO_2	UOP, Wisconsin Power, Aerojet, Ohio Corp., Peabody & Wellman Powers (Olin Corp.), Johnstone
Soda Sulfite	Na_2SO_3	"	Electrolysis	H_2SO_4	Stone & Webster Ionics
Potassium sulfite bisulfite	K_2CO_3,K_2SO_3	$KHSO_3$,$K_2S_2O_5$	–	SO_2, H_2SO_4	Tampa Electric, Wellman-Lord, Olin-Matheson
Ammonia	NH_4OH	$(NH_4)_2SO_3$, NH_4HSO_3, $(NH_4)_2SO_4$	H_2SO_4	SO_2, S, $(NH_4)_2SO_4$	Simon Carves, Olin-Matheson, Trail, Kiyoura, Mitsubishi, Showa Denka, Guggenheim
Ammonia (Guggenheim, Cominco)	NH_4OH	NH_4HSO_3	Steam,H_2SO_4,CaO, Coke, CH_4	$CaSO_4$,NH_3,S	ASARCO, ICI, Trail, Mitsubishi, Showa Denka, Wade, TVA
Ammonia-zinc oxide	NH_3	NH_4	ZnO	SO_2	U.S. Bureau of Mines (Morgantown)
Ammonia-hydrazine	NH_3,N_2H_4	$(N_2H_5)_2SO_3$, $(N_2H_5)_2SO_4$	Steam	SO_2,N_2H_4, $(NH_4)_2SO_4$	Aerojet General
Wet lime-limestone	$CaCO_3$,CaO	$CaSO_3$, $CaSO_4$	–	–	Bechtel Still, Howden ICI, Combustion Engr., TVA, Zurn Babcock & Wilcox, Peabody, A.B. Banco (Research Cottrell) Battersea, UOP
Basic aluminum sulfate	$Al(OH)SO_4$	$Al(OSO_2H)SO_4$, $Al(OSO_3H)SO_4$	CaO, $CaCO_3$	$CaSO_4$, SO_2	ICI, Outokumpu Oy, Boliden
Magnesium oxide and hydroxide (Chemico-basic)	MgO,$Mg(OH)_2$	$Mg(HSO_3)_2$, $MgSO_3$, $MgSO_4$	NH_3	$(NH_4)_2SO_4$, H_2SO_4, MgO, SO_2	Boston-Edison, Chemical Const. Corp., Babcock & Wilcox, U.S.S.R.
Manganese oxide and magnesium hydroxide	$Mg(OH)_2$, MnO_2	$MgSO_4$,$MnSO_4$, MnS_2O_6	Coal	S, H_2S, SO_2,MnO_2	Zinkendustrie, Wilhelm Grillo, TVA
Formate	KOOCH	$K_2S_2O_3$	Steam, CO_2, CO	H_2S, S	Consolidation Coal
Citrate	Sodium citrate	HSO_3 complex	H_2S	S	U.S. Bureau of Mines (Salt Lake City)
		Low Temperature Aqueous Sorption and Regeneration			
Sulfidine	Xylidine or toluidine	–	–	SO_2	Norddeutsche Affinerie
Organic scrubber	Glyrol, Amine	–	Steam	SO_2	Arthur D. Little
		Medium Temperature Liquid or Solid Sorption and Regeneration			
DMA(brimestone)	Dimethy analine	SO_2	Reformed CH_4	S	ASARCO - Phelps Dodge
Reinluft	Activated charcoal	SO_3	Steam	SO_2,H_2SO_4	Commonwealth Assoc., Reinluft, Hitachi, Bergbau, Torschung
Boliden	Coke	–	–	S	Boliden, ICI, Trail, Cominco, Billingham
Catalytic oxidation	V_2O_5 or NO_2 catalysts	SO_3	NH_3	SO_3,H_2SO_4, $(NH_4)_2SO_4$	Metropolitan Edison, Monsanto-Penelec, Tyco, Kiyoura, SNPA-Topoe, Ill. Power
Alkalized alumina	N_2O,Al_2O_3	Na_2SO_4,Al_2SO_4	Reformed CH_4	S, H_2S	CEGB, U.S. Bureau of Mines (Bruceton)
Alkali	Nahcolite	–	–	SO_4^{-2}	Precipitator Pollution Control
Alkaline-earth	CaO, MgO	$MgSO_4$	CO	C, $CaSO_4$, $MgSO_4$	Battelle, Combustion Engr., Wikert, CRIEPI, TVA, Steinkohlen-Elektrizitat
Lignite ash	CaO	$CaSO_3$	–	SO_2, CaO	Carl Still
MnO_2 (DAP)	MnO_2,ZnO	$MnSO_4$,$ZnSO_4$	NH_4OH	$(NH_4)_2SO_4$, SO_2, MnO_2	Mitsubishi, Aerojet
CuO	Cu + Al oxides	$CuSO_4$	CH_4, H_2	S	UOP, Exxon, Shell, U.S. Bureau of Mines (Bruceton)
Liquid SO_2	Liquidification	SO_2	–	–	Tacoma, Canadian Ind. Ltd., Copper Cliff Spanish Smelter
Molten carbonate	Carbonates of Li, Na, K	SO_3^{-2} and SO_4^{-2} of Li, Na, K	C + H_2O, CO + H_2	H_2S	Atomics International, Consolidated Edison, Garrett, North American Rockwell
Liquid claus	–	–	H_2S	S	Institut Francis du Petrole, Nippon, UOP
Solid claus	–	–	Al_2O_3,H_2S	S	Princeton Chemical Research
Transition metal on alumina	–	–	Oxides, CO	S	Chevron Research, U.S. Bureau of Mines (Twin Cities)
Flyash	–	–	Flyash, CH_4	S	GATX
Low temperature reduction	–	–	Oxides, CH_4, CO, H_2	S	Allied Chemical, Texas Gulf Sulfur
Direct reduction	–	–	Oxides, CH_4, C	S	Outokumpu Oy

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to a Stretford section where hydrogen sulfide is converted to elemental sulfur. Final tail gas concentrations in the range of 40 to 80 ppm sulfur (as sulfur dioxide) have been reported for the process. The process flow sheet is shown in Figure 101.

The Beavon process effectively recovers sulfur from carbonyl sulfide and carbon disulfide as well as from hydrogen sulfide. Operation of the Beavon process requires supplemental fuel gas. Beavon recovers sulfur in its elemental form as a by-product. The process condensate may require further treatment prior to discharge.

D-1.4.2 SCOT Process

Figure 102 shows a simplified SCOT process flow chart. The catalytic reactor converts organic sulfur to hydrogen sulfide according to the following reactions:

$$COS + H_2O \longrightarrow H_2S + CO_2$$
$$CS_2 + 2H_2O \longrightarrow 2H_2S + CO_2 \quad (89)$$

Sulfur dioxide and free sulfur react as follows:

$$SO_2 + 3H_2 \longrightarrow H_2S + 2H_2O \quad (89)$$
$$S + H_2 \longrightarrow H_2S \quad (96)$$

Alkanolamine scrubbing removes the hydrogen sulfide from the tail gas stream. The hydrogen sulfide can be recovered in an hydrogen sulfide stripper and recycled to the sulfur recovery process. Reports indicate treated tail gas have a total sulfur content of 200 to 500 ppm by volume. The SCOT process requires additional fuel gas to provide

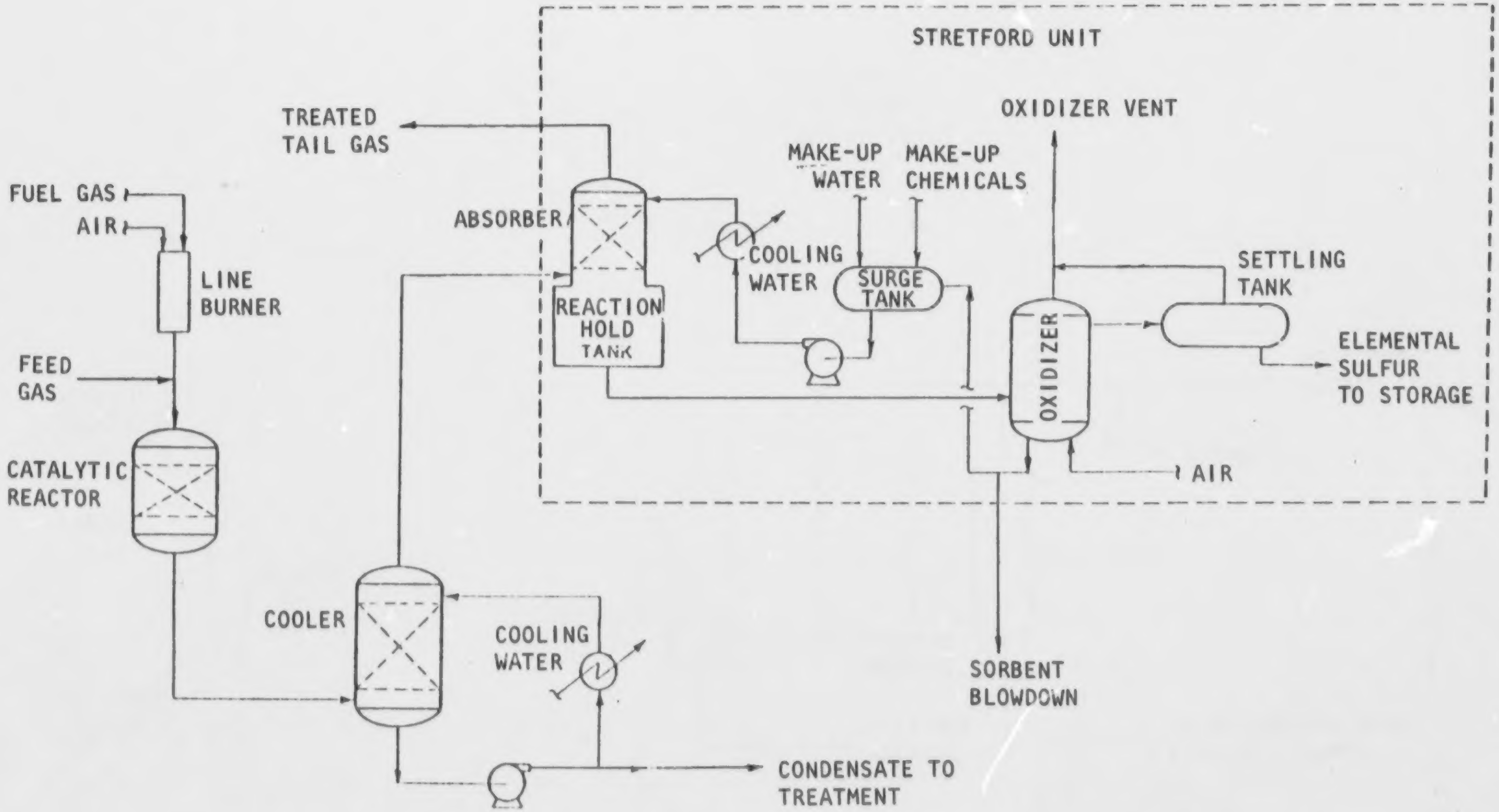
STRETFORD UNIT
TREATED TAIL GAS
OXIDIZER VENT
MAKE-UP WATER
MAKE-UP CHEMICALS
FUEL GAS
AIR
ABSORBER
COOLING WATER
SURGE TANK
SETTLING TANK
LINE BURNER
REACTION HOLD TANK
OXIDIZER
ELEMENTAL SULFUR TO STORAGE
FEED GAS
CATALYTIC REACTOR
AIR
COOLER
COOLING WATER
SORBENT BLOWDOWN
CONDENSATE TO TREATMENT

Figure 101. Beavon tailgas cleanup process

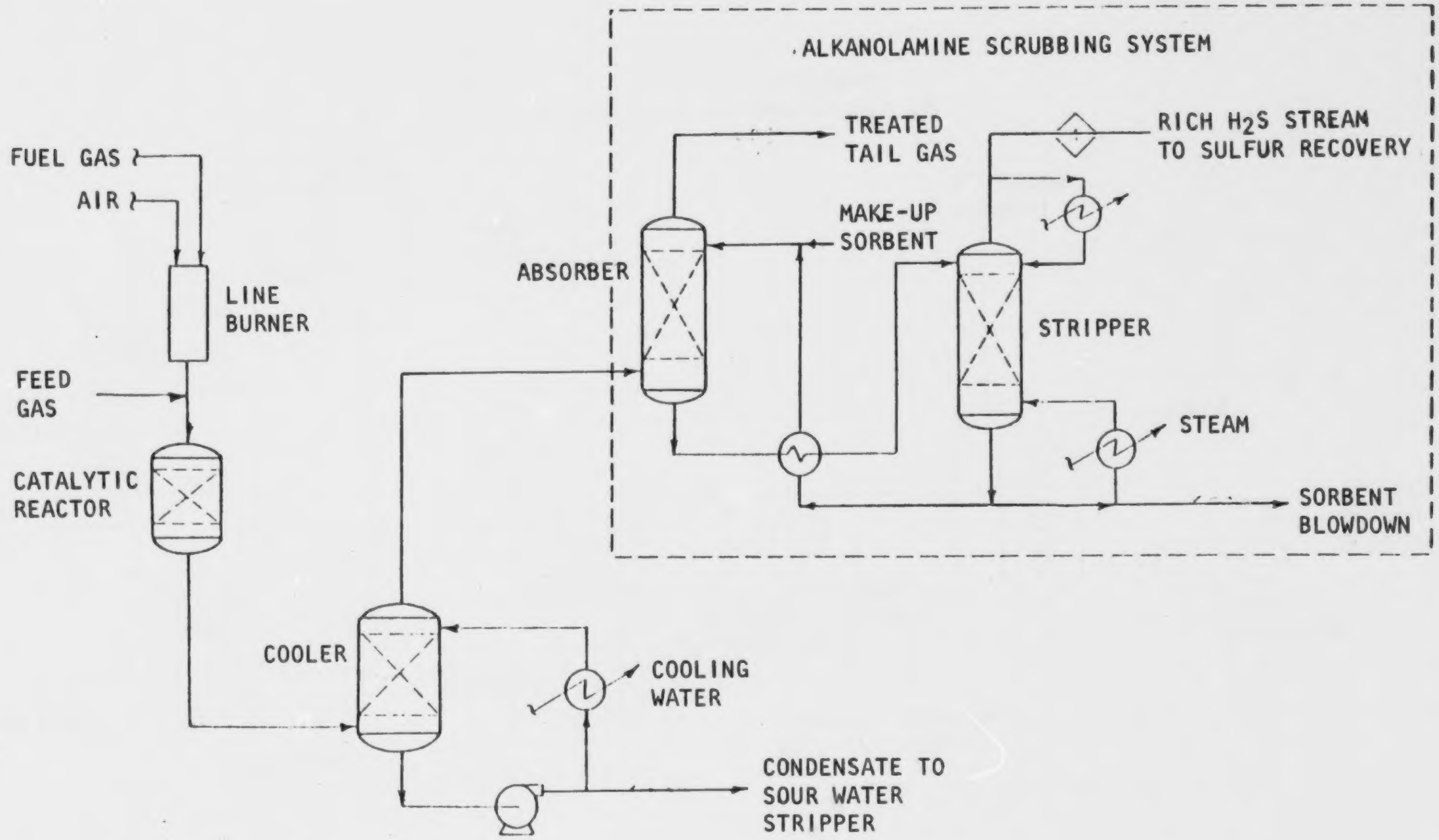
ALKANOLAMINE SCRUBBING SYSTEM
FUEL GAS
AIR
LINE BURNER
FEED GAS
CATALYTIC REACTOR
COOLER
COOLING WATER
CONDENSATE TO SOUR WATER STRIPPER
ABSORBER
TREATED TAIL GAS
MAKE-UP SORBENT
STRIPPER
RICH H_2S STREAM TO SULFUR RECOVERY
STEAM
SORBENT BLOWDOWN

Figure 102. SCOT process

reducing gas and heat for the reactor section. The equipment utilized is proven and removal efficiencies higher than reported are theoretically possible.

D-2 Water Effluent Control Alternatives

Water effluent control processes may be divided into three classes according to their treatment function, i.e., primary, secondary or tertiary treatment. Table 135 lists the general classes of treatment methods and applicable processes within each class which may be employed in a coal liquefaction plant.

TABLE 135. PROCESSES FOR WATER EFFLUENT CONTROL

	Class of Treatment	
Primary	Secondary	Tertiary
Equalization	Biological treatment	Filtration
Sedimentation	Flocculation/flotation	Carbon adsorption
Neutralization		Advanced:*
Oil and Grease Separation		Electrodialysis Reverse osmosis Ion exchange
Recovery Processes		
Ammonia Phenol Sulfur		
Stripping		

*Advanced process for sidestream treatment in water cooling process.

In the selection of control alternatives, the most significant pollutants to be removed from each wastewater stream must first be determined. Then it must be decided whether to segregate or integrate various wastewater streams prior to treatment. Also, it must be decided if any stream constituents may be recovered. Once the chemicals to be recovered and main treatment systems needed to treat various wastewater streams have been identified, then the appropriate pretreatment (primary) and post treatment (tertiary) methods may be selected.

The following sections deal with the various treatment operations included under the three classes of treatment.

D-2.1 Primary Treatment

Primary treatment units are designed to remove wastewater stream constituents which may adversely affect the operation of the main treatment processes and/or may be recovered economically. Applicable primary treatment operations are enumerated in Table 135.

D-2.1.1 Recovery Operations

In SRC systems, there are a number of pollutants, namely, sulfur, ammonia, and phenols, which may be recovered economically from the wastewater streams. Although they are, by definition, auxiliary processes, they are, in essence, primary (pretreatment) treatment processes. If it had not been economically feasible to recover these compounds, then it most likely would have been necessary to incorporate various treatment methods into the overall treatment process to remove them or render them harmless.

D-2.1.2 Sedimentation

Sedimentation is a solids-liquid separation process whereby suspended solids are separated from water and concentrated by gravity settling. This type of separation is effective when the suspended solids are capable of settling readily as is the case for domestic wastewaters. Often, wastewaters may contain finely divided suspended matter which does not settle easily. Chemical coagulants are usually added in these instances to agglomerate the suspended matter into larger particles which exhibit improved settling characteristics. Typical coagulants are alum, ferric chloride, and aluminate. Popular coagulant aids are bentonite, powdered carbon, activated alumina, and polyelectrolytes.

Sedimentation removal efficiencies vary widely depending on the nature of the influent suspended matter. A well designed and operated tank should remove between 50-60 percent of the influent solids (93).

Sedimentation tanks may be either rectangular or circular. The detention times in circular tanks is usually between 90-150 minutes with surface loading not to exceed 36.7 $m^3/day/m^2$ (93).

The design of rectangular sedimentation tanks is usually based on the wastewater flow, solids loading, and settling characteristics. The horizontal velocity through the chamber is given by the following equation (93):

$$V = V_s \frac{L}{d}$$

where* V = maximum horizontal velocity (ft/sec)

V_s = terminal settling velocity of the particle to be removed (ft/sec)

L = length of basin (ft)

d = depth of basin (ft)

The terminal settling velocity in ft/sec may be estimated from the following equation (93):

$$V_s = \frac{(\rho_s - \rho\ell)\, gD^2}{18\mu}$$

where: ρ_s = density of solid particle (lb/ft^3)

$\rho\ell$ = density of wastewater (lb/ft^3)

D = diameter of solid particle (ft)

μ = viscosity of wastewater (lb/sec-ft)

g = acceleration of gravity (32.2 ft/sec^2)

Horizontal velocities are usually less than or equal to 0.3 m/s (93). This fixes the size of the chamber for a given flow rate.

---

*Metric conversion factors are given in the appendices.

Tube settlers may also be used to remove suspended matter in lieu of sedimentation basins. They essentially act as a series of rectangular basins, where water enters the bottom of the inclined tube settler and flows upward through the tubes. Particles tend to move toward each tube wall where they become entrapped in a layer of particles previously settled. The steep incline of the tubes causes the sludge to counterflow along the side of the tubes after it accumulates. In then falls into a sediment storage sump below the tubes assembly. The inclined tube settler configuration also requires influent and effluent chambers to distribute the flow to the tubes and to collect if after clarification.

Inclined tube settlers are manufactured with tubes having various geometrically-shaped cross sections. Systems employing flocculation with inclined tube settlers are capable of removing particles less than 10 microns in diameter (fine sand). They are usually used to clarify influent waters which have under 1000 mg/l of suspended solids (157). The number of tubes may be increased to provide treatment for virtually any flow rate desired.

The horizontal velocity through the settler is given by the following equation (151):

$$V = \frac{Vs\ L\ \cos A}{d}$$

where: A = angle of inclination $\left(0.0 \le A \le \tan^{-1} \frac{L}{d}\right)$

Tube settlers are generally designed for flows of 3.4×10^{-3} to 5.4×10^{-3} $m^3/s/m^2$ (158).

In addition to sedimentation basins, screening devices may also be used to remove suspended solids. Separator screens normally consist of rectangular or circular structures supporting wire mesh screens. Water is introduced directly onto the screen surface. Solids are detained on the surface while the screened water exits downward. Trapped solids are vibrated to the outer periphery of the screen element for disposal. Typical separator screens may remove particles ranging from a few hundred microns in diameter to as small as 45-50 microns (157). Screen designs are based on the screen opening and solids loadings which can be accommodated without blinding the screen. The sedimentation removal rate decreases with decreasing size of particles removed.

D-2.1.3 Steam Stripping

Steam stripping may be used to remove hydrogen sulfide, ammonia, and phenol from a wastewater stream. Depending on the operating temperature and pressure, the ammonia and hydrogen sulfide content of the raw feed, the type of system - refluxed or nonrefluxed and the number and efficiency of trays or packing, approximately 98-99 percent of the hydrogen sulfide and 95-97 percent of the ammonia present in the raw feed stream may be removed (159). It has also been observed that up to 40 percent of any phenols present in the raw feed may also be removed by this process (159).

The volume of steam required in this process has been found to vary between 0.11 and 0.13 kg of steam per liter of tower feed (159). As high as 0.24 kg per liter have been used. Typical design parameters include 8-10 trays, a tower pressure of 3.4×10^4 to 2.1×10^5 Pa, and a tower temperature of 110-132°C. The stripper volume will depend on the composition of the feed stream and the number of trays required to produce the desired effluent.

This process has an advantage over air stripping processes in that chemical addition is not required and additional compounds can be removed.

D-2.1.4 Equalization

Equalization is a process whereby the composition of a wastewater stream is made uniform and the volumetric flow rate constant. It is normally required when a number of streams with highly variable chemical compositions and flow rates are combined for treatment. The addition of equalization facilities to a treatment plant improves the efficiency, reliability, and control of subsequent physical, chemical and/or biological treatment processes.

Equalization basins are normally designed with a preset detention period for chemical mixing (i.e., 15-30 minutes) based on the average daily flow, or, in the case of highly variable flows, to retain a sufficient portion of the wastewater stream, while maintaining adequate freeboard, in order that a predetermined constant flow rate is discharged to the treatment plant (160).

D-2.1.5 Neutralization

When biological treatment processes are used to treat industrial wastes, the influent wastewater stream pH should be between 5.0 and 10.0. Extreme pH wastewaters may be adjusted within these units by the addition of acids or bases. Common reagents used for neutralization are summarized in Table 136.

TABLE 136. NEUTRALIZATION REAGENTS

Acid Wastes	Alkaline Wastes
Waste alkalis	Waste acids
Limestone	Sulfuric acid
Lime slurry	Hydrochloric acid
Soda ash	Sulfur dioxide
Caustic soda	
Ammonia	

Selection of neutralization reagents is based primarily on cost considerations. Reagent solubility, neutralization reaction rate, neutralization end products, and ease of operation also require consideration.

The process flow scheme used for neutralization depends on the neutralization reagent(s) employed, desired degree of neutralization and waste flow characteristics. Depending on the rate of waste flow, either continuous or batch-wise neutralization is employed. Generally continuous neutralization is used when the waste flow exceeds 4.4×10^{-2} m^3/s. Detention times of 10-30 minutes are typical (158).

D-2.1.6 Oil and Grease Separators

Oily wastes may be grouped in the following classifications:

- Light Hydrocarbons - These include light fuels such as gasoline, kerosene, and jet fuel, and miscellaneous solvents used for industrial processing, degreasing, or cleaning purposes. The presence of these light hydrocarbons may encumber the removal of other heavier oily wastes.

- Heavy Hydrocarbons (Fuels and Tars) - These include the crude oils, diesel oils, #6 fuel oil, residual oils, slop oils, and in some cases, asphalt and road tar.
- Lubricants and Cutting Fluids - These are generally in two classes, non-emulsifiable oils such as lubricating oils and greases, and emulsifiable oils such as water soluble oils, rolling oils, cutting oils, and drawing compounds. Emulsifiable oils may contain fat, soap or various other additives.

These compounds can settle or float and may exist as solids or liquids, depending upon such factors as method of use, production process, and temperature of wastewater.

Primary oil-water separators are designed to remove free oils readily separated from a wastewater stream. This process provides a reduction in the oxygen demand of the wastes (both BOD and COD) and reduces operational difficulties caused by oils and grease in subsequent biological treatment processes.

Gravity separators are most commonly used to remove free oils from wastewaters. The difference in densities of oil or grease and water will cause free oily wastes to rise to the surface of the wastewater, where they are collected and removed by skimming devices.

The parameters considered in the design of oil-water separators are: (1) rate of rise of oil globule, (2) minimum horizontal area, (3) minimum vertical cross-sectional area, and (4) minimum depth to width ratio. Design equations are given in Table 137.

The horizontal and vertical areas and the depth to width ratio fix the size of basin to be used.

D-2.2 Secondary Treatment

Biological treatment and flocculation/flotation are the two main treatment processes most commonly employed for wastewaters similar to those found in coal liquefaction processes. When flocculation/flotation is needed, it usually precedes the biological treatment system.

D-2.2.1 Flocculation/Flotation

Air flotation is a process whereby suspended matter, including both suspended solids and insoluble oily wastes, is separated from water. This process is often used in conjunction with gravity oil/water separators when there are significant quantities of both free and emulsified oils present in wastewaters.

Air flotation separates oil globules from the wastewater by introducing tiny air bubbles into the flotation chamber. The air bubbles attach themselves onto oil globules dispersed throughout the water. The resultant buoyancy of the oil globule - air bubble complex causes it to rise to the water's surface where it is removed by surface skimming devices. Air flotation processes are classified as dispersed

TABLE 137. GRAVITY OIL-WATER SEPARATOR DESIGN EQUATIONS (6)

---

(1) $V_t = 0.0241 \frac{(S_w - S_o)}{\mu}$

(2) $A_h = F\, Q_m/V_t$

(3) $A_c = Q_m/V_h$

(4) $d/B = 0.3$

where* V_t = rate of rise of a 0.015 cm diameter globule, (ft/min).

S_w = specific gravity of wastewater at design temperature

S_o = specific gravity of oil in wastewater at design temperature.

μ = absolute viscosity of wastewater at design temperature (poises).

A_h = minimum horizontal area (ft^2)

Q_m = wastewater flow (ft^3/min)

F = correction factor for turbulence and short circulating in separator (see Figure 103)

A_c = minimum vertical cross-sectional area (ft^2)

V_h = horizontal flow velocity (fpm), not to exceed 3 fpm

d = depth of wastewater in separation (ft)

B = width of separator channel (ft).

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*Metric conversion factors are given in the appendices.

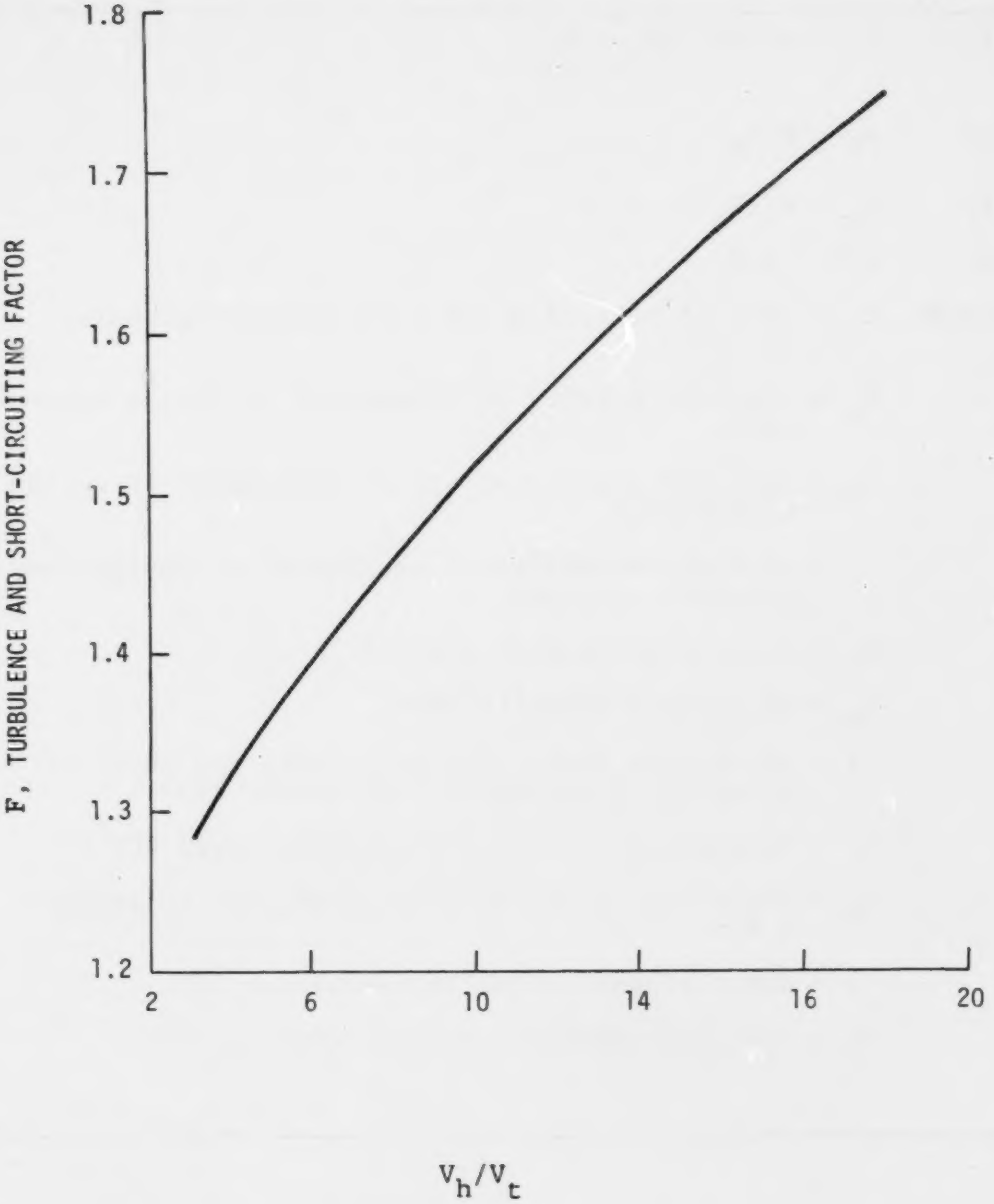


Figure 103. Recommended values of F for various values of V_h/V_t

air or dissolved air depending upon the method of air introduced into the flotation unit. Pressure dissolved air flotation units are most commonly employed in industrial wastewater treatment. The basic equation governing the separation of oil from water is given below (158):

$$V_t = \frac{g\, D^2(\rho_o - \rho_w)}{18\mu}$$

Where*

V_t = terminal velocity attained by suspended solids passing through water (ft/sec)

g = acceleration of gravity (32.2 ft/sec^2)

D = diameter of suspended impurity (ft)

ρ_o = density of oil in waste (lb/ft^3)

ρ_w = density of wastewater (lb/ft^3)

μ = viscosity of wastewater (lb/sec-ft)

Based on this principle, the following design criteria have been recommended for rectangular flotation chambers (158):

- The ratio of depth to width should be between 0.3 and 0.5.

---

*Metric conversion factors are given in the appendices.

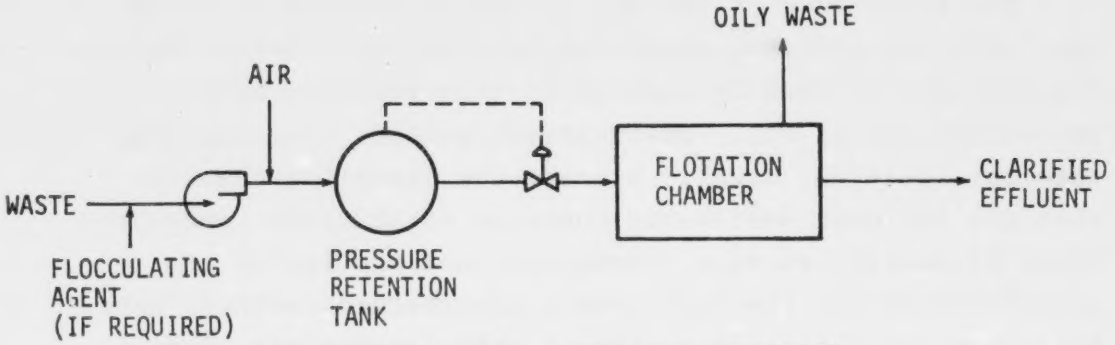
- The maximum ratio of the horizontal water velocity to particle rise velocity is recommended to be 15.
- The maximum horizontal water velocity is recommended to be 1.5 cm/s.
- The optimum length to width ratio is set at 4 to 1.
- A maximum width of 6.7 m is recommended.

Typical operating parameters are given in Table 138.

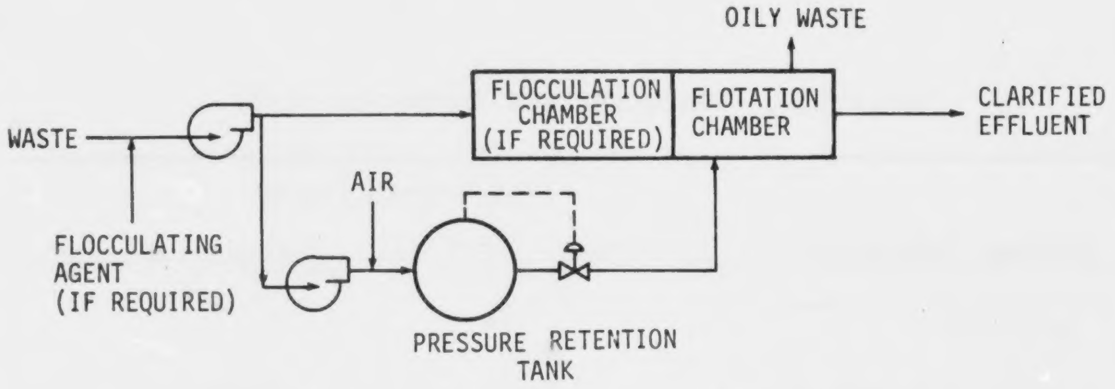
TABLE 138. AIR FLOTATION UNIT OPERATING CONDITIONS (158)

Parameter	Value
Residence time in flotation chamber	10-40 minutes
Residence time in pressurization tank	1-2 minutes
Hydraulic loading in flotation chamber	41-244 l/m^2-minutes
Oily waste loading	9.8-19.5 $kg/hr\text{-}m^2$
Air requirement (full flow operation)	0.075 scm/m^3

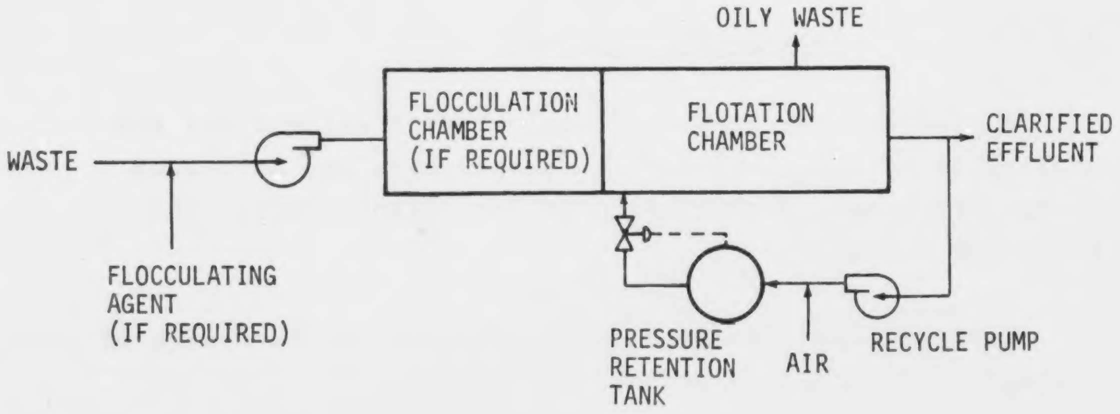
There are three basic flow schemes employed for the pressure type dissolved air flotation process. They are designated as full-flow operation, split-flow operation, and recycle operation. Full-flow operation is the most general form of the process. Split-flow operation is used primarily to remove oily wastes from wastewaters of low suspended solids concentration, while the recycle operation is used when a delicate floc is present in the influent wastewater stream. These operations are shown in Figure 104 (158).


OILY WASTE
AIR
WASTE
FLOTATION CHAMBER
CLARIFIED EFFLUENT
FLOCCULATING AGENT (IF REQUIRED)
PRESSURE RETENTION TANK

AIR FLOTATION PROCESS: FULL-FLOW OPERATION


OILY WASTE
FLOCCULATION CHAMBER (IF REQUIRED)
FLOTATION CHAMBER
CLARIFIED EFFLUENT
WASTE
AIR
FLOCCULATING AGENT (IF REQUIRED)
PRESSURE RETENTION TANK

AIR FLOTATION PROCESS: SPLIT-FLOW OPERATION


OILY WASTE
FLOCCULATION CHAMBER (IF REQUIRED)
FLOTATION CHAMBER
CLARIFIED EFFLUENT
WASTE
FLOCCULATING AGENT (IF REQUIRED)
PRESSURE RETENTION TANK
AIR
RECYCLE PUMP

AIR FLOTATION PROCESS: RECYCLE OPERATION

Figure 104. Three flow schemes employed in the dissolved air flotation process

The efficiency of the air flotation process is dependent upon the influent water characteristics. Water containing free oil is readily removed by this process, while emulsified oil is not. Pretreatment methods, encompassing chemical addition, usually precede the flotation chamber when the influent wastewater contains significant concentrations of emulsified oils. Coagulation/flocculation and acidification are the most common pretreatment methods used. Dissolved air flotation treatment efficiencies are given in Table 139.

TABLE 139. DISSOLVED AIR FLOTATION (158)

	Oil Removal, Percent	
Treatment Description	Floating or Free Oil	Emulsified Oil
Flotation without chemical pretreatment	70-95	10-40
Flotation with chemical pretreatment	75-95	50-90

D-2.2.2 Biological Treatment

The three basic types of biological treatment systems applicable to coal liquefaction wastewaters are activated sludge processes, aerated lagoons (oxidation ponds), and trickling filters.

Important parameters to be considered in the design of biological treatment processes are:

- BOD loading
- Oxygen availability
- Temperature

- pH
- Toxicity
- Dissolved salts

Design parameters for various biological treatment systems are given in Table 140.

The treatment process required for any industrial wastewater will mainly depend on the biodegradability of the waste, cost considerations taking into account other unit processes which may be required, and the degree of treatment required. For example, wastes which degrade very slowly will require longer detention times than wastes which degrade rapidly. This would most likely necessitate the use of lagoon systems in lieu of conventional systems.

In addition to the basic biological treatment unit, secondary clarifiers are also integral components of the biological treatment system. The clarifiers serve two functions: to settle out suspended matter from the biological aeration basin effluent and to recycle a portion of the solids to the aeration basin.

The secondary clarifiers are normally designed for 4-6 hours detention based on the average daily flow (93). Surface loading rates and weir loading rates do not normally exceed 36.7 m^3/day/m^2 and 126 m^3/day/m, respectively (93). The recycle volume from the clarifier to the aeration basin usually ranges from 30-100 percent of the influent flow (93). In the case of trickling filters, there is no recirculation of solids to the filter in standard rate filter systems. In high rate filters, however, the recycle ranges from 100-400 percent of the influent flow (93).

TABLE 140. BIOLOGICAL TREATMENT SYSTEMS (93)

Process	Loading kg BOD/day/m^3	Detention Time (hours)	Treatment Efficiency (percent)
Activated sludge			
Extended aeration	0.16-0.40	18-36	75-95
High rate aeration	1.6-16.0	0.5-2	75-90
Conventional	0.32-0.64	4-8	85-95
Aerated Lagoon		72-240	80-95
Stablization Ponds	0.32-0.80	240-720	80-95
Trickling Filters			
Standard rate	0.14-0.22		85
High rate	1.11		65-75

D-2.3 Tertiary Treatment

Tertiary treatment basically consists of physical-chemical processes which polish or refine the effluents from secondary processes to within acceptable limits either for discharge to surface water or for plant reuse. Some tertiary treatment processes are filtration, carbon adsorption, ion exchange, electrodialysis, and reverse osmosis.

D-2.3.1 Filtration

There are numerous filtration processes which may be used to polish secondary effluent wastewaters. Filtration processes applicable to coal liquefaction wastewaters are given in Table 141 along with design parameters. Filtration processes may be divided into two classes: deep bed filtration and polishing filtration. Microscreening and vacuum filtration are considered polishing filtration while gravity and pressure filters are considered deep bed filtration.

There are three types of deep bed filtration systems which will be described: gravity downflow, gravity upflow, and pressure filters.

Deep bed filtration utilizes a bed of granular filter media to separate suspended matter from water. These systems are usually applicable up to 1,000 mg/l of solids with particle sizes ranging from 0.1 to 50 (161). Since the entire filter media is available to capture solids, a clear filtrate is produced.

Downflow filtration involves the filtration of water in a downward direction through progressively coarser filter media. Upflow filtration involves the filtration of water

TABLE 141. FILTRATION PROCESSES

Process	Filter Media	Loading (1pm/m^2)	Solids Removal Capacity kg/unit area	Efficiency (Suspended Solids Removal)
Microscreening	Garnet	81-407	---	45-85% (5 mg/1)
Gravity filters				
Downflow	Coal Sand	81-244	0.14-0.23 (one layer)	50-90%
	Garnet	81-244	0.23-0.45 (multi-layer)	80-90%
Upflow	Coal Sand Garnet	81-244	0.23-0.45	50-90%
Pressure filters	Coal Sand	81-407	0.14-0.23	90%
Vacuum filtration	Diatomaceous earth	20-41	---	98%

in an upward direction through progressively finer filter media. Prevention of the movement of the filter materials is accomplished by the use of restrictive screens and grids. Polyelectrolytes can be added to the sediment-laden influent for further solids removal by these filters. Pressure filters rely on pumps to force sediment-laden wastewaters either upward or downward through a filter media.

The loading rates are essentially the same for both gravity downflow and upflow filters. The use of upflow filter is generally more advantageous because the filter runs are usually longer and consequently the number of backwashings required are reduced. The use of downflow filters is somewhat disadvantageous because sufficient hydraulic head must be available for successful operation of the filter. A disadvantage of the upflow filter is loss of filter material during the normal operating cycle.

Pressure filters are basically more advantageous than gravity filters for wastewater applications because they can handle higher solids loadings and higher pressure heads and are more compact and less costly. A major disadvantage is the difficulty encountered in servicing the filters when they malfunction. The filter is completely enclosed.

Those parameters which must be considered in the design of deep bed filters are available head loss, filtration rate, influent characteristics, media characteristics, and filter cleaning system. Media characteristics have been found to be the most important considerations in the design of deep bed filters. Media particle size determines the performance and operation of the filter. It has been observed to be inversely proportional to both filtrate quality and pressure drop across the filter. A distribution of particle sizes (multi-media beds) enables the filter to be utilized more efficiently in that it will not clog as readily as a filter containing only one filter medium. Multi-media filters consequently require less frequent backwashing.

Polishing filters such as the diatomaceous earth vacuum filter are capable of removing suspended solids in the micron and submicron range from very dilute aqueous suspensions. Although they are capable of producing a high quality effluent, the occurrence of varying quantities of influent suspended solids has led to erratic operation of this filter in tertiary treatment operations. A microscreen consists of a rotating drum with a fine screen around its periphery. Feed water enters the drum through an open end and passes radially outward through the screen, depositing solids on the inner surface of the screen. At the top of the drum, pressure jets of effluent water are directed onto the screen to remove the deposited solids. A portion of the backwash water penetrates the screen and dislodges solids, which are captured in a waste hopper and removed through the hollow axle of the unit. Particles as small as 20-40 microns may be removed by this system. Disadvantages include incomplete solids removal and inability to handle solids fluctuations.

D-2.3.2 Carbon Adsorption

Carbon adsorption is usually employed as a tertiary treatment unit for the removal of soluble organic matter in wastewaters. Approximately 70-90 percent of the influent BOD and 60-75 percent of the influent COD may be removed by this process when it is preceded by secondary biological treatment (162).

Carbon adsorption design considerations include adsorptive capacity of the carbon, wastewater flow and characteristics and method of carbon contacting. The general range of hydraulic flow rates are 1.4×10^{-3} to 6.8×10^{-3} $m^3/s/m^2$ (118). Bed depths are typically 3.3-10 m (162). The maximum area for good flow distribution is 93 m^2 (162).

The alternatives for carbon contacting systems include: downflow or upflow contacting, series or parallel operation, pressure or gravity downflow contactors, and packed or expanded bed upflow contactors. Upflow beds have an advantage over downflow beds in that there is a minimum usage of carbon. Upflow expanded beds are able to treat wastewaters relatively high in suspended solids and can employ finer carbon (reduces contact time) without excessive headloss. A disadvantage of the upflow packed bed is that it requires a high clarity influent. The principal use of the downflow contactor is to adsorb organics and filter suspended materials. Pressure downflow contactors increase the flexibility of operation since they allow the system to be operated at higher pressure losses.

The carbon dosage required depends on the strength of the wastewater feed and the desired effluent quality. Rough estimates of the carbon dosage required for secondary biological effluents plus filtration are 48-72 Mg/m^3 of wastewater (162).

Bench scale tests determine more quantitatively the carbon dosages needed to produce a desired effluent. The carbon column contact time (empty bed basis) is generally 6.8×10^{-3} to 3.4×10^{-2} $m^3/s/m^2$ (162).

D-2.3.3 Reverse Osmosis

The reverse osmosis process is capable of removing particles from water in the range of 0.0004-0.06 microns. Removal efficiencies range from 90 to 99+ percent in most cases (163).

The principal use of reverse osmosis is for purification of brackish waters. It is also used as water pretreatment for ion exchange deionization to make ultrapure water for subsequent use as boiler feed, cooling tower makeup, and washwater of essentially zero hardness. Organic matter is also removed by this process which offers a significant advantage over demineralization systems such as ion exchange or electrodialysis.

Measures required to reduce the incidence of membrane fouling represent a significant disadvantage of the reverse osmosis process in terms of operation and cost. Membrane fouling is due to biological growth, manganese and iron, suspended solids scale, and/or organics. Pretreatment is generally required to reduce the incidence of fouling which consequently increases the capital and operating costs considerably over other processes. Pretreatment measures commonly used are chlorination to control biological growth, polishing filters to reduce suspended solids levels, softening to reduce scale, and precipitation of iron and manganese as ferric hydroxide and manganese dioxide.

The most important parameters considered in the design of a reverse osmosis plant include recovery, product water quality, brine flow rates, the necessary degree of pretreatment, flux maintenance procedures, and post treatment.

The design flux, expressed in m^3/m^2/day, is a function of the feed composition, temperature, and pressure. Given the operating conditions and influent flow rate, the membrane area required can be determined. Membrane manufacturers should supply these data. The product water quality can be determined by iterative techniques from the following equations (169):

1. $$C_{ip} = \frac{C_{ip}\left(1 \quad (R_i)_{avg}\right)}{Z - \left(\frac{Q_p}{Q_f}\right)}$$

2. $$Q_f = Q_c + Q_p$$

3. $$Q_f C_{if} = Q_c C_{ic} + Q_p C_{ip}$$

4. $$C_{im} = \frac{Q_c C_{ic} + Q_f C_{if}}{Q_c + Q_f}$$

5. $$C_{ip} = C_{im}\left(1 - (R_i)_{avg}\right)$$

where:

C_{ip} = concentration of salt i in product stream (mg/l)

C_{if} = concentration of salt i in feed stream (mg/l)

Q_p = volumetric flow rate of product (l/min)

Q_f = volumetric flow rate of feed stream (l/min)

$(R_i)_{avg}$ = average salt rejection by membrane

C_{im} = mean local brine concentration on upstream side of membrane (mg/l)

C_{ic} = concentration of salt i in concentrate stream (mg/l)

Qc = volumetric flow rate of i in concentrate stream (l/min)

Pretreatment and post-treatment methods are designed based on influent water constituents and effluent limitations.

D-2.3.4 Ion Exchange

Ion exchange is a process whereby ions that are held by electrostatic forces to charged functional groups on the surface of a solid are exchanged for ions of similar charge in a solution in which the solid is immersed. This process is used extensively in water and wastewater treatment, primarily for the removal of hardness ions such as calcium and magnesium. A series of cationic and anionic ion exchangers (demineralization) are also often used to produce water of high purity for industrial applications.

The design of ion exchangers is based on the ion exchange capacity of the selected ion exchange resin. The basic resin usually consists of a three dimensional matrix of hydrocarbon radicals to which are attached soluble ionic functional groups. There are two types of ion exchange resins, namely, cationic and anionic. Cationic resins have positively charged functional groups such as hydrogen or sodium attached to the hydrocarbon radicals, while anionic resins have negatively charged functional groups such as hydroxide or chloride ions attached to the hydrocarbon radicals. The ability of the resin to adsorb ions is the ion exchange capacity expressed in kg/m3. Each resin has a different capacity which must be specified by the manufacturer of the resin. Also, resins have observed preferences for certain ions which must be considered in the selection of a particular resin.

Once the resin has been selected, the volume of resin required may be determined from the following equation (177):

$$R = \frac{QT}{C}$$

where:

R = cubic meters of resin required

Q = equivalents of ions which must be removed per day to meet certain effluent limitations (i.e. 90-99 percent removal for two stage operations)

T = selected operating period (days) beyond which the effluent limitations will be exceeded and the resin requires regeneration (economic selection based on cost of regeneration chemicals and required removal efficiency)

C = ion exchange capacity of resin in equivalents/day

The depth of the exchanger is usually at least 50 percent greater than the depth of the resin to allow for expansion during backwash and regeneration (163).

Other factors to be considered in the design of ion exchangers are the flow rate and volume of chemicals needed to regenerate the ion exchange resin. Flow rates of 4.1×10^{-3} to 6.8×10^{-3} $m^3/s/m^2$ are typical (163). Typical regenerant solutions are sodium chloride, sulfuric acid, sodium hydroxide, sodium carbonate, ammonium hydroxide, and hydrochloric acid. Cost considerations and type of ion exchanger dictate the chemicals to be used. Since it is not the intention of ion exchangers to remove large quantities of suspended solids, filtration usually precedes the ion exchange process. If filtration was not normally required for a particular wastewater, then it must be included in the cost considerations for selecting the ion exchange process.

Typical removal efficiencies for the ion exchange process preceded by biological treatment and filtration are given in Table 142.

TABLE 142. REMOVAL EFFICIENCY OF ION EXCHANGE (93)

Wastewater Constituent	Percent Removal
BOD	40-60
COD	30-50
NH_3	85-98
organic nitrogen	80-95
NO_3	80-90
PO_4	85-98
dissolved solids	depends on resin used

D-2.3.5 Electrodialysis

The electrodialysis process is capable of removing particles in the range of 0.0004-0.1 microns (93). The removal efficiency for wastewaters which have been treated by biological processes, filtration, and carbon adsorption is approximately 40 percent (93).

Parameters used in the design of electrodialysis systems are dilute cell compartment velocity, cell power input, cell current, product concentration, current efficiency, cell resistance. Experimental analyses are usually performed for a significant wastewater constituent such as sodium chloride. The first four parameters listed above are measured in a specific volume electrodialysis cell. The current efficiency, required membrane area, power requirements, and energy requirements may be determined from the following equations using the experimental results (163):

- $n = \frac{Q_d(\Delta N_i)\ F}{I}$
- $Q_d = WtI$
- $Ap = \frac{Q_d F}{(1000)n} \ \frac{(N_d)}{i_{lim}} \ \ln \frac{N_f}{N_p}$
- $R_p = (P/I^2)LW$
- $i = I/Ao$
- $P = \frac{Q_d{}^2 F^2}{Ap} \left(N_f - N_p\right) \left(\frac{(R_p N_d)\ln\ N_f}{n^2 \qquad N_p}\right)$
- $Na = \frac{C}{1000(MW)}$
- $E = P/Q_d$

- $N_o = Q/24(Q_d)$
- $A = N_oA_p$
- $\bar{P}_t = P\ N_o$

where:

Q_d = flow rate in dilute compartment (ml/s)

$\Delta Ni = N_f - N_p$ = difference in feed and product water normalities

F = Faraday's constant = 96,500

I = input current (amps)

n = current efficiency

W = width of test cell (cm)

t = thickness of test cell (cm)

A_p = effective required cell area (cm^2)

N_d = waste product concentration of wastewater constituent (equivalents/l)

i_{lim} = limiting current density = i (amps)

N_f = feed wastewater constituent concentration (equivalents/l)

N_p = effluent wastewater constituent concentration (equivalents/l)

R_p = cell area resistance (ohm-cm^2)

C = concentration of wastewater constituent (gm/equivalents)

MW = molecular weight of wastewater constituent (gm/equivalents)

E = energy requirements (kWhr/1000 gal product)

N_o = number of cells required

Ao = area of test cell (cm^2) = LW

$\bar{P}_t$ = total power required (KW)

P = test power (W)

L = length of test cell (cm)

Na = definition of normality of wastewater constituent (equivalents/1)

P = power required per cell (W)

D-3 Solids Treatment Alternatives

This section discusses control alternatives applicable to the treatment of sludges generated within the SRC plant and from the operation of the wastewater treatment facilities. A representative survey of applicable equipment has been included.

Solids treatment encompasses solids volume reduction and/or treatment processes designed to render solid wastes harmless for ultimate disposal by improving their handling characteristics, reducing their volume, and/or reducing their leachability. Typical control equipment available to accomplish these objectives is listed in Table 143. Each type of equipment is discussed separately.

TABLE 143. SOLIDS TREATMENT

Volume Reduction Processes	Treatment Processes
Thickeners	Wet oxidation
Filter press	Pyrolysis
Centrifuges	Incineration
Rotary vacuum filter	Lime recovery
Lagoons	Heat drying
Other processes:	
Moving screen concentrators	
Belt pressure filters	
Capillary dewatering	
Rotating gravity concentrators	

D-3.1 Volume Reduction Processes

Sludge volume reduction processes are, most often, essential components of a wastewater treatment facility when a significant quantity of sludge must be disposed of. Economically, it is more advantageous to dispose of sludge which has a low moisture content and is relatively compact. The dewatering equipment listed in Table 143 is capable of providing a significant reduction in the moisture content of wastewater sludges.

The selection of dewatering equipment depends on the characteristics of the sludge, the method of final disposal, availability of land, and economics involved.

D-3.1.1 Thickeners

There are three basic classes of thickeners: gravity, dissolved air flotation, and centrifugal. Design parameters for each class of thickener are given in Table 144 (170). Performance of these units is dependent upon the solids loading, hydraulic loading, and removal efficiencies.

Dissolved air flotation thickeners are preferred over gravity thickeners because of their reliability, thicker product, higher solids loading, lower capital cost, and better solids capture. The operating costs, however, are higher for the flotation unit. Centrifugal and dissolved air-flotation units are generally used for excess activated sludge while gravity units may be used for both primary and excess activated sludge.

D-3.1.2 Filter Press (Pressure Filtration)

The design of filter presses depend on the quantity of waste sludge to be processed and the desired daily filter press operating period. Often, chemical conditioning agents must be added to the sludge prior to being applied to the filter press to aid in the dewatering process. Typical aids are ferric chloride ash, and lime. It has been observed that the moisture content of pressed sludges ranges from 40-70 percent (164).

TABLE 144. DESIGN PARAMETERS FOR THICKENERS

	Class			
		Dissolved	Centrifugal	
Parameters*	Gravity	Air Flotation	Disc	Solid Bowl
Hydraulic loading		Max. acceptable	NA	NA
Solids loading	P. A.S.		NA	NA
Air/solids rates	NA		NA	NA
Percent solids inlet	P. 2.5-5.5 A.S. 0.5-1.2	0.5-1.2	0.7-1.0	0.5-1.5
Percent solids outlet	P. 8-10 A.S. 2.5-3.0	4	4-7	5-13
Percent solids recovery		90	80-97	65-95
Recycle ratio (percent)	NA	30-150	NA	NA
Pressure	NA		NA	NA
Flow range	NA	NA		
Detention time (hours)	24	0.33	NA	NA
Thickener depth		NA	NA	NA

P. = primary sludge A.S. = activated sludge NA = not applicable

*Data presented are typical parameters used for domestic wastewater solids. Consequently, thickeners do not have to be designed strictly within these limits. Also, data on dissolved air flotation and centrifugal units are presented for excess activated sludge.

Approximately 1 to 3 hours is required to press a sludge to the desired moisture content (93). The whole process, including the time required to fill the press, the time the press is under pressure, the time to open the press, the time required to wash and discharge the cake, and the time required to close the press varies from 3-8 hours (93).

Advantages of this process are high cake solids concentration, improved filtrate quality, improved solids capture, and reduced chemical consumption. Disadvantages include batch operation, high labor costs, filter cloth life limitations, operator incompatibility, and cake delumping.

D-3.1.3 Centrifuges

The three basic types of centrifuges which may be used to dewater sludges include solid bowl (countercurrent and concurrent), basket and disc. Polymeric flocculants are most often used with this type of equipment. The use of flocculants is dependent upon the characteristics of the sludge to be dewatered.

Hydraulic capacities and applications of the three types of centrifuges are given in Table 145. The theoretical maximum capacities of these centrifuges are given by the following equations (164):

For basket and solid bowl centrifuges;

$$T = \frac{L_e w^2}{2g} \left(3r_2{}^2 + r_1{}^2\right)$$

TABLE 145. CHARACTERISTICS OF CENTRIFUGES (165)

Centrifuge	Hydraulic Capacity	Application
Basket	up to 227 lpm decrease to 151 lpm	Metal hydroxide wastes, aerobic sewage sludges, water treatment alum sludges
Solid bowl	to 151 lpm as low as 284 lpm	Raw primary or mixed primary & biological sludges (domestic), anaerobically digested primary or mixed sludges, and heat-treated of limed chemical sludges. It may be applied at high cost to excess activated sludge, aerobic digested sludges, and alum or ferric chemical sludges. In water treatment, it is excellent on water softened lime sludges.
Disc	78-1135 lpm 1151 lpm	Excess activated sludge for feed concentrations of 0.3 to 1.0 percent suspended solids.

For disc centrifuges;

$$T = \frac{2\ nw^2}{3g\tan\emptyset}\left(r_o{}^3 - r_i{}^3\right)$$

where*

T = theoretical capacity

L_e = effective length of settling zone (ft)

w = angular velocity in centrifugal zone (radian/sec)

r_2 = radius of inside wall of cylinder (ft)

r_1 = radius of the free surface of the liquid layer in the cylinder (ft)

g = acceleration of gravity (32.2 ft/sec^2)

n = number of spaces between discs

d = half the included angle of the discs

r_o = radius of outside measure of the disc (ft)

r_1 = radius of inside measure of the disc (ft)

Variables of importance which affect the performance of centrifuges include bowl design, bowl speed, pool volume, conveyor design, relative conveyor speed, and sludge feed rate.

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*Metric conversion factors are given in the appendices.

The hydraulic loadings which may be applied to each centrifuge is a function of Q/T, where, Q is the flowrate and T is the theoretical capacity of the centrifuge.

Solids concentrations of 15 to 40 percent have been observed from various centrifuges (164). Solids capture ranges from 80-95 percent for oxygen activated sludges (170). For excess activated sludges, a higher degree of dewatering may be expected from a basket centrifuge than from a disc centrifuge. Typically, basket centrifuges have been found to concentrate solids in the range 0.5-1.5 percent to approximately 10-12 percent. Given the same sludge, disc centrifuges can concentrate the solids to only 6 percent. Also, 90 percent solids capture is possible in the basket centrifuge with no chemical addition (164).

In many cases, two or more types of centrifuges may be operated in series to increase the solids concentration of sludges. A typical design may include a disc centrifuge to thicken a sludge followed by a solid bowl centrifuge.

Disc centrifuges have a high clarification capability but possess an upper limit on the size of particle which can be handled. Feed waters should be degritted and screened prior to entering this equipment.

D-3.1.4 Rotary Vacuum Filters

Rotary vacuum filters consist of a cylindrical rotating filter partially submerged in an open tank filled with the slurry to be filtered. The filter elements can be coated with a substance such as diatomaceous earth or other precoat material so that particles much finer than the openings in the filter element can be retained.

Vacuum filters operate at low differential pressures, on the order of 0.04-0.07 MPa (164). When a precoat substance is utilized on a vacuum filter, particles down to about 1 micron in diameter can be removed, resulting in very clean effluents. Influent slurries, however, usually must be limited to less than a one precoat solids concentration. The vacuum filter can be cleaned by hosing, internal sluicing, or air pump backwashing.

The use of vacuum filters is governed by the media's opening and size distribution of particles in the sludge. It has been observed that the solids captured by vacuum filters may range from 85-99.5 percent depending on the type of filter media, chemical conditioning, and solids concentration in the applied sludge. Cake yields usually range from 2.7 - 20 $g/s/m^2$ for domestic sludges. The surface area of vacuum filters generally ranges from 4.6-28 m^2. Estimated performance for design purposes is usually taken to be 4.7 $g/s/m^2$ (dry weight basis) (164).

The filtrate discharge rate and cake thickness left on the filter may be calculated by the following equations (165):

$$Z_c = 60n \ \frac{V_f}{A} \ = \ \frac{7200(\ P)Bn}{W} \ 1/2$$

$$L_c = \frac{1}{60 \quad c^n} \ \underline{7200B(\ P)nW} - Z_c W_f$$

where*

Z_c = filtrate in gph/ft^2 total area

n = cycles per minute

V_f = volume filtrate (gal)

A = filter area (ft^2)

P = pressure differential maintained across the leaf (psi)

B = fraction of total area actually being filtered at any given time

= specific resistance of cake (to be calculated)

= viscosity of filtrate (lb/sec-ft)

W = mass of dry solids/volume of slurry (lb/gal)

c = density of cake (lb/ft^3)

W_f = solids content of filtrate (lb/gal filtrate)

L_c = cake thickness (ft)

The quality of the filter cake is measured by the percentage moisture content of the cake on a weight basis. A typical range of moisture contents which may be expected from this equipment is 60-80 percent (164).

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*Metric conversion factors are given in the appendices.

Typical chemical conditioning agents for the raw sludge are lime and ferric chloride.

D-3.1.5 Lagoons

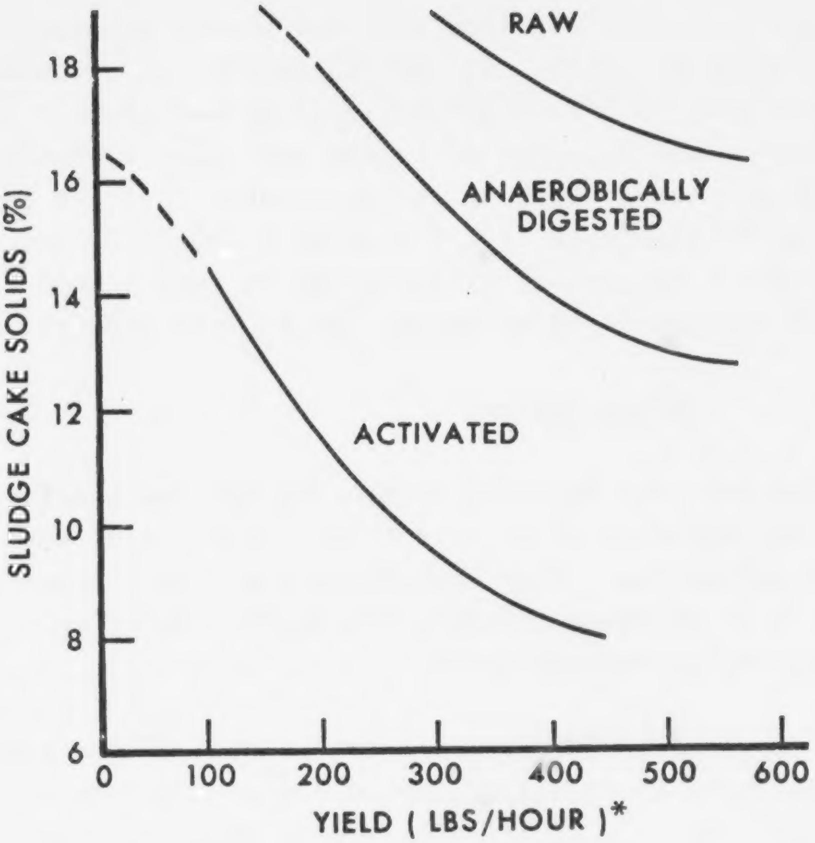
Drying lagoons are most ideally used where there is a great deal of land and the climate is hot and arid. Lagoon depths are generally not more than 0.6 m with loading rates of 35-38 kg/yr/m^3 (164). Sludge can usually be removed from the lagoon in 3 to 5 months (164). If it were feasible to load a lagoon for a period of 1 year and allow a drying period of 2-3 years, then it is conceivable that the applied sludge may be dewatered from 5 percent to 40 to 50 percent solids (164). An obvious disadvantage of this method is the extensive time required to obtain the desired product.

D-3.1.6 Other Systems

There are four types of dewatering systems manufactured by various companies which do not fall into any of the previous categories. They include moving screen concentrators, belt pressure filters, capillary dewatering, and rotating gravity concentrators.

Moving screen concentrators are capable of processing 182-364 kg/hour of excess activated sludge and 364-728 kg/hour of primary sludge (164). These concentrations have been reported to increase the solids content of primary sludges to 20 to 30 percent (164). Typical yields vs. sludge cake solids are shown in Figure 105. These units handle thickened polymer treated sludges.

Belt pressure filters have been reported to produce mixed sludge concentrations of 25 to 30 percent (164). Polymer aids are generally used with these filters.



*Metric conversion factors are given in the Appendices.

Figure 105. Moving belt concentrator yield vs. cake solids*

Pilot scale studies on domestic sludges using capillary dewatering systems have indicated that loading rates of 7.25 $g/s/m^2$ will produce cake solids of 14-19 percent with solids recoveries of 50-90 percent (164). Polyelectrolytes and ferric chloride were used as filter aids in these systems.

The rotating gravity concentrator has been mainly employed as a concentrating device when more complete dewatering was required. In one instance, it was reported that a 25 percent filter cake was produced from a 6 percent raw primary sludge (164). A disadvantage of the system is the short life of the dewatering belt.

D-3.2 Treatment Processes

In addition to dewatering equipment there are numerous processes which may be required in a wastewater treatment plant to render solids wastes harmless prior to ultimate disposal, to recover valuable chemicals, and/or to make subsequent processes operate more efficiently. Typical processes include heat drying, wet oxidation, pyrolysis, incineration, and lime recovery. In many cases, one or more of these processes may be combined with appropriate dewatering equipment to produce sludges acceptable for ultimate disposal.

D-3.2.1 Heat Drying

Heat treatment may be used in lieu of chemical pretreatment to improve the dewatering characteristics of sludges. In this process, sludge may be thickened to approximately 7 to 11 percent by breaking down particle structures within the sludge. Operating conditions are generally 182°C and 1.2 MPa (166). The detention time is approximately 30 minutes (166). Up to 379 liters per minute can be processed by this method. It has been observed that, in many instances, the moisture content of sludges may be reduced to lower levels by using heat drying than by chemical addition.

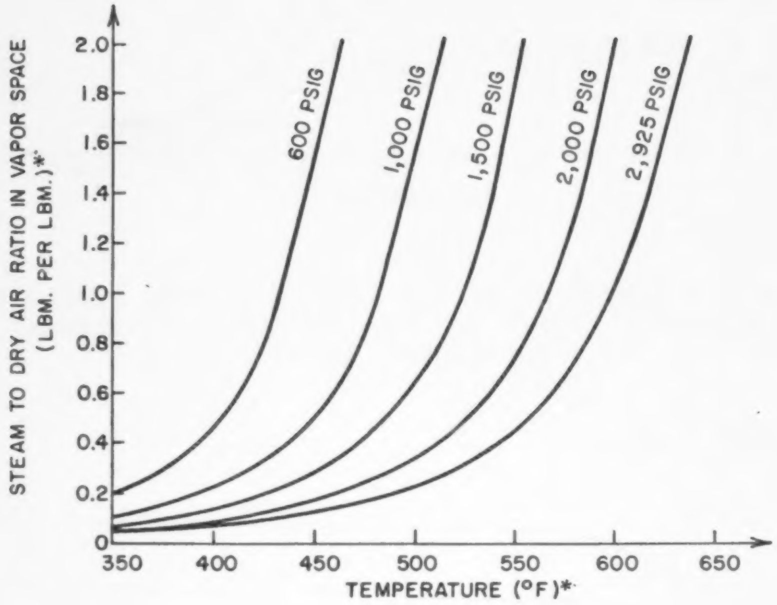
D-3.2.2 Wet Oxidation

The wet air oxidation process is based on the principle that any substance capable of burning can be oxidized in the presence of liquid water at temperatures of 121°-371°C. It is excellent for waste sludges which do not dewater easily. Typical operating conditions are given in Table 146. Figures 106, 107, and 108 provide operating conditions as a function of each other.

TABLE 146. WET AIR OXIDATION PROCESS OPERATING CONDITION (172)

Operating Condition	Value(s)
Feed COD	25-150 g/1
Temperature	149-316°C
Pressure	2.1-13.7 MPa
COD reduction	5-80%
VSS reduction	30-98%

Four important parameters which control the performance of the oxidation process are temperature, air supply, pressure, and free solids concentration. The degree and rate of sludge solids oxidation are significantly influenced by the reactor temperature. It has been observed that higher degrees of oxidation and shorter retention times are possible with increased temperatures. The air requirements are based on the heating value of the sludge and the degree of oxidation desired. Operating pressures must be carefully controlled to prevent excess water vaporization in the oxidation reactor.



*Metric conversion factors are given in Appendix B.

Figure 106. Steam-to-air ratio at saturation in the reactor vapor space for various operation temperatures and pressures (166)

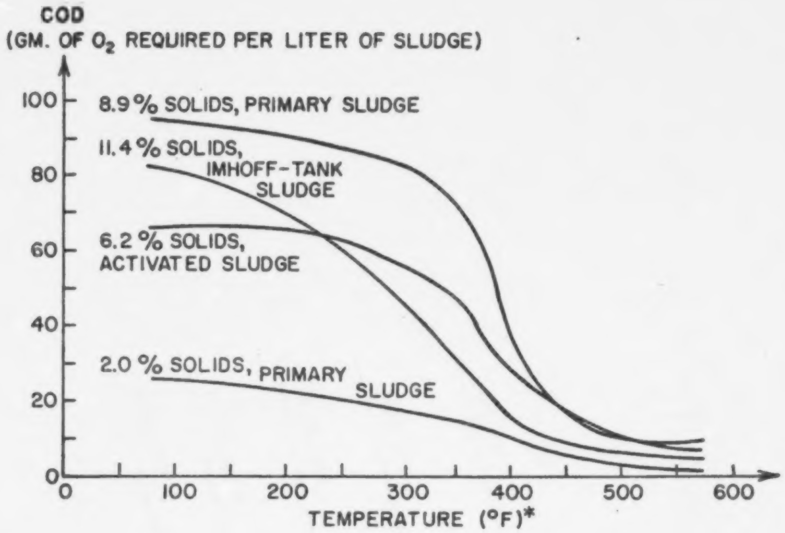
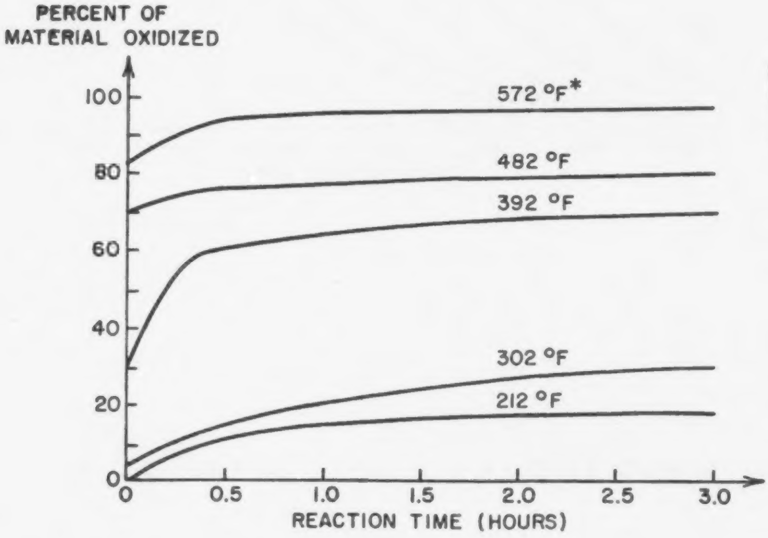


Figure 107. Reduction in COD resulting from sludge being exposed to excess air for one hour at various temperatures (166)



*Metric conversion factors are given in Appendix B.

Figure 108. High operation temperatures result in high COD reduction and low reaction time (166)

Advantages and disadvantages of the process are listed in Table 147.

TABLE 147. WET OXIDATION PROCESS

Advantages	Disadvantages
does not require dewatering no air pollution	need stainless steel construction materials
produces easily filtered and biodegradable end products	need to recycle wet air oxidation liquors, high in organic content, phosphorus, and nitrogen back through the plant
potential to generate or recover steam, power and chemicals	
flexible in degree of oxidation and type of sludge handled	possible frequent shut-down and maintenance problems
	odor problems

D-3.2.3 Pyrolysis

Pyrolysis involves the destruction of longchain organic materials by high temperature exposure. Retorts, rotary or shaft kilns, or fluidized beds are used to pyrolyze waste sludges. This process has been proposed as an alternative to incineration since it partially disposes of solid wastes. Volume reduction also occurs in the process. It has an advantage over incineration methods because it eliminates air pollution problems and produces useful by-products. Little data has been published, as yet, on the pyrolysis of sludges.

D-3.2.4 Incineration

Incineration is a two stage process including drying and combustion. It is most often used to render offensive sludge wastes harmless so that the sludge may be safely disposed of in landfills. The most commonly used incineration processes are the multiple hearth furnace and the fluidized bed furnace.

Considerations important in the design of incineration processes are the following:

- familiarity with state and local air and water quality regulations and with occupational, health and safety standards
- nature and amount of sludge to be incinerated
- applicability of incineration processes to sludge treatment
- auxiliary fuel and excess air requirements
- economics

The composition of industrial sludges may vary so widely from one plant to another that standard incineration processes are usually not applicable. Hence, special incinerators must be designed to handle the complex compounds found in these sludges. Often more than one incinerator must be provided to combust complex organic materials formed in the first incineration process.

Multiple hearth furnaces have been adapted to numerous uses including burning of raw sludge, digested sludge and sewage greases; recalcination of lime sludges; and pyrolysis operations. Capacities generally range from 91 to 3636 kg/hr dry solids (166). Combustion zone temperatures range from 760 to 927°C) (166). Fluidized bed incinerators are most often used for sewage sludge disposal. Capacities range from 100 to 2273 kg/hr dry solids (166). Operating temperatures range from 704 to 816°C (166).

Although well-designed incinerators are relatively simple to operate and maintain, a major disadvantage resulting from the process is the air emissions which must be controlled. Advantages and disadvantages of incineration are listed in Table 148.

TABLE 148. INCINERATION

Advantages	Disadvantages
Less land required for disposal of incinerated sludges	Large initital expenditures
Incinerator residue is free of food for rodents and insects	Disposal of remaining residue must be provided
Incinerators can burn a variety of refuse materials	Air pollution
Adverse weather conditions should have no effect on incineration process	Possible incomplete reduction of waste materials
Incineration construction is flexible	High stacks needed for natural draft chimneys present safety problems

D-3.2.5 Lime Treatment

Lime treatment is a process whereby lime is recovered from a waste sludge. Economic considerations dictate whether or not this process should be included in industrial wastewater treatment facilities.

The lime treatment process typically includes dewatering devices such as thickeners or vacuum filters, centrifuges, a furnace, lime cooler, classifier, and lime storage unit. The design of thickeners, vacuum filters, and furnaces has been previously discussed. Contactive (direct) heat transfer methods may be used to cool the resultant furnace residue prior to directing it to the classifiers. Centrifuges (also previously discussed) may be used prior to the furnace to purge the sludge of inert solids. They also reduce the required furnace volume. Dry classifiers are used after the furnace to separate the calcium oxide from the residue. This is accomplished by air separations based on particle size. The regenerated calcium oxide is then sent to a lime storage tank for reuse.

D-4 Final Disposal Alternatives for Solid Wastes

There are numerous wastes resulting from SRC systems and from the operation of wastewater treatment facilities which may be ultimately disposed of on land. Wastes discharged to land may be in the liquid or solid phase. Typical land disposal methods include spreading on soil, lagooning, dumping, landfilling, composting, spray irrigation, and evaporation ponds. The first five are considered sludge disposal techniques while the latter two are considered liquid waste disposal techniques. State, federal, and local regulations, availability of land, applicability of ultimate disposal processes, and economics will dictate which of the aforementioned methods may be employed to ultimately dispose of liquid and solid wastes.

D-4.1 Sludge Disposal

Land disposal of sludges includes the application of sludge on soils used for crops or other vegetation, and the stockpiling of sludges on land. Stockpiling refers to the disposal of sludges in mines, quarries, landfills, and permanent lagoons. An inherent disadvantage of land disposal is that it is not a permanent solution because the sites fill and new locations must be found.

D-4.1.1 Land Spreading

Land spreading encompasses the disposal of sludge on soils used for crops or other vegetation and on lands occupied by abandoned strip mines. Sludge may be spread on the land as a soil conditioner or as an organic base for fertilizers (biological sludges). It also serves as a source of irrigation water. Other areas where land spreading may be applicable are forest regeneration, development of new parklands and institutional lawns, and top dressing for parklands.

There are six acceptable methods of land application including: plow furrow cover, contour furrow, trenching, subsod injection, spray or flood irrigation, and spreading (solid) (167). The application method selected will depend on physical properties of the sludge, quantity of sludge, acceptable application rate, site characteristics, crops grown, site management, and public acceptance. Land spreading of both liquid and dewatered sludges are feasible by the above methods. An analysis of liquid sludge transport costs vs. dewatering equipment costs must be undertaken when there are no regulations restricting the moisture content of the sludge to determine the most economic means of sludge disposal.

Spray and flood irrigation systems are applicable only to the disposal of liquid sludges. This method may be used year round with proper maintenance on crop covers located on

0.5 to 1.5 percent sloping lands (167). Power requirements may be significant when stationary application systems are used. Flood irrigation is less costly than spray irrigation, but can only be used in basin shaped sites. Problems resulting from this method include fly breeding, odors, and a tendency of solids to settle out near the outlets.

The plow furrow cover method may be used for both liquid and dewatered sludge application. Sludge may be applied in a plow furrow manner using trucks, wagons or irrigation systems. This method eliminates odor and pest problems but is not usable on wet or frozen soils and on highly sloped lands.

Contour furrows are normally used for the application of liquid sludges. This method leaves the soil in only a partially plowed condition.

Subsurface injection is reserved for the disposal of liquid wastes. The site must be level or slightly sloped and must not be wet, hard, or frozen.

Trenching may be used for both liquid and dewatered sludges. Problems encountered with this method include possible groundwater pollution and difficulty in keeping the sludge where placed during backfilling operations.

Spreading applies only to the disposal of dewatered sludges. This method encompasses the spreading of sludges on reasonably dry solid surfaces with bulldozers, loaders, graders or manure spreaders, and plowing it under.

It has been recommended that several alternative land spreading methods should be made available at each site to coincide with weather conditions, presence of crops, poor quality sludge (odors) and equipment breakdown.

D-4.1.2 Lagooning

Sludge lagooning is a simple and economical method of sludge disposal especially in remote locations. Sludges can be stored, indefinitely in this type of system or removed periodically to other sites after draining and drying. Lagoons are usually 1.3 to 1.7 meters deep. This method is usually feasible only when there are large tracts of land available for dedication to lagoons.

D-4.1.3 Dumping

Dumping is a process whereby stabilized sludge is deposited in abandoned mines and quarries. Where available, this provides an alternative to other disposal methods.

D-4.1.4 Landfills

Sanitary landfills are the most widely used type of landfill. In many cases, it is permissible to mix domestic and industrial waste sludges for disposal in a sanitary landfill.

Criteria commonly used in the selection of a suitable landfill site include the following:

- The site should have a relatively low permeability and low water table.

- The site should be far enough away from surface water bodies or shallow wells.
- A liner and drain system is recommended at the site.
- The site should be covered with an impervious layer to maximize runoff.
- Vector control should be provided.
- A wooded barrier should be provided.

Sludges applied to a landfill site should be dewatered as much as possible to minimize the quantity of free water which may leach out of the sludge.

Application rates will depend on sludge composition, soil characterisitcs, climate, vegetation, and cropping practices. Loading rates of 0.056 to 11.2 kg/m^2 are common (166).

Problems associated with the use of landfills include the following:

- groundwater pollution
- surface water pollution
- land requirement
- health hazards

- landfill gases (explosive)
- aesthetic effects on neighboring communities.

D-4.1.5 Composting

Composting requires larger tracts of land than other stabilization methods and produces a solid product which must be disposed of. Its uses are similar to those for land spreading, namely, as a soil conditioner and organic base for fertilizers. Considerations with regard to site selection and maintenance are also similar to land application methods previously discussed. Land requirements are 0.17 m^2/kg of sludge using the forced air, static pile process. Advantages and disadvantages of the process are listed in Table 149.

TABLE 149. COMPOSTING

Advantages	Disadvantages
• odor free product • easy to store product • able to return nutrients and organics to soil • nitrogen levels are reasonably low	• cost of transport to composting site may have high levels of heavy metals • requires large tracts of land • product requires further disposal

D-5 Accidental Release Technology

Accidental releases of pollutant materials from a coal conversion process are very similar to those encountered in a conventional petroleum refinery. Generally, there are two main categories of accidental releases: material spills, and gaseous venting during emergency operating conditions.

Spills are the result of leaks from tanks, pipes, valves, and fittings; ruptures in storage and process equipment; overfilling of tanks; and poor operation and maintenance processes in general. Material spills in coal conversion plants are mostly on land rather than on water. However, land spilled pollutants may find their way into the aquatic environment via groundwater contamination, so proper prevention, control, and cleanup procedures are essential to maintain environmental integrity.

Provisions must be made to handle huge quantities of process gases released by pressure release valves during emergency operating conditions. These emergency conditions occur due to compressor failures, loss of cooling water, vessel overpressure, power failures, fires, and other emergency conditions. It is common practice to tie all emergency relief valve outlets, along with any continuous waste gas streams, into a common header system that vents to a flare system.

Preventive and countermeasure techniques will be discussed with respect to material spills within the plant. A description of the types of flare systems that can be used for emergency venting will then be discussed.

D-5.1 Material Spill Prevention

There are a number of engineering practices which can be applied to a material spill prevention program and they are discussed below:

Leaks from storage tanks seem to be an ever present source of soil and groundwater contamination in oil refineries. Leaks develop when the tank bottom undergoes significant corrosion, and so many prevention practices involve the control of tank corrosion and include:

- Insure that structural materials are compatible with the material being stored.

- Assess structural integrity for conformance to code construction.

- Contained water promotes corrosion. Proper methods for draining water from tank bottoms should be employed. Figure 109 shows several commonly used methods for draining tank bottoms. It is also possible to develop automatic methods employing oil/water interface sensors such as density sensors, conductivity sensors, and dielectric constant sensors.

- Repair of leaks and corrosion must be prompt, no matter how minor. Leaks may be repaired by patching while the tank is in service, and numerous products are commercially available for patching.

- Buried carbon steel tanks should be coated, wrapped, and lined. Depending on the nature of the soil, cathodic protection may be appropriate. Partially buried carbon steel tanks can set up galvanic corrosion and increase the rate of corrosion at the soil/air interface.

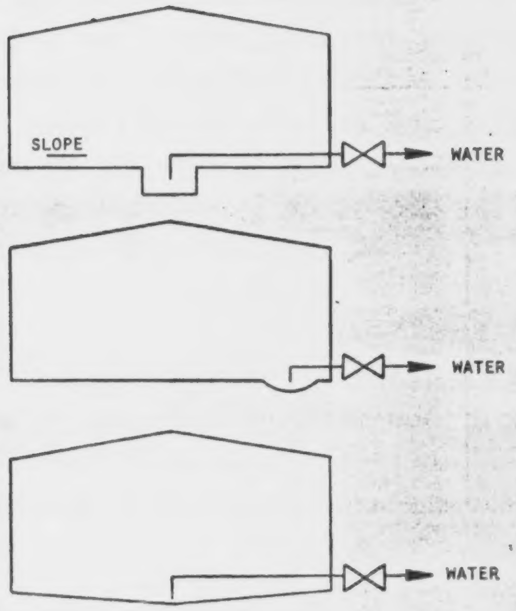

SLOPE
WATER
WATER
WATER

Figure 109. Tank bottom drainage systems (168)

- Tanks should be examined periodically for evidence of external leakage (especially bottoms). This examination may consist of visual inspection, hydrostatic testing, and/or nondestructive shell thickness testing.

  Shell thickness may be measured by ultrasonic analysis. Inspection records should be kept on a frequency basis that is consistent with the historical failure rate of tanks in the same service.

- Corroded tanks should be lined and coated with epoxy. This treatment fills small pits and crevices and prevents inside corrosion.

  Normally, tanks are sandblasted to remove rust, dirt and scale which not only prevents product contamination but prepares the interior surface for epoxy coating. The coating needs to be selected for its compatibility with the material stored. X-ray analysis will locate pits and crevices.

- Deteriorated bottoms should be replaced with inverted cone-type bottoms. Figure 110 illustrates one technique for replacement of tank bottoms.

- Mobile storage tanks should be isolated from navigable waters by positioning and containment construction.

  One of the most common sources of leaks and spills is the mobile storage tank such as the diesel fuel tank used for construction machinery. It is

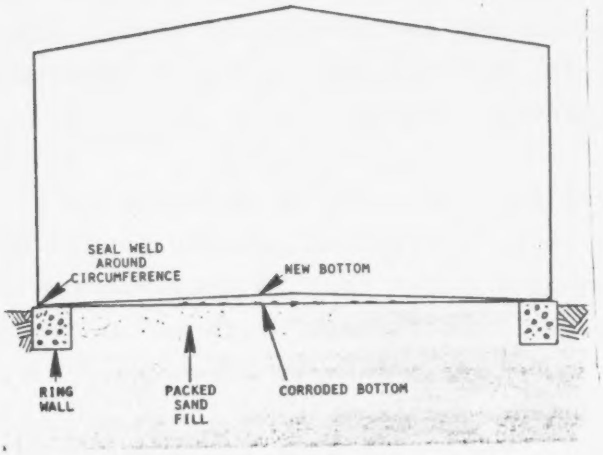

SEAL WELD
AROUND
CIRCUMFERENCE
NEW BOTTOM
RING
WALL
PACKED
SAND
FILL
CORRODED BOTTOM

Figure 110. Tank bottom replacement (168)

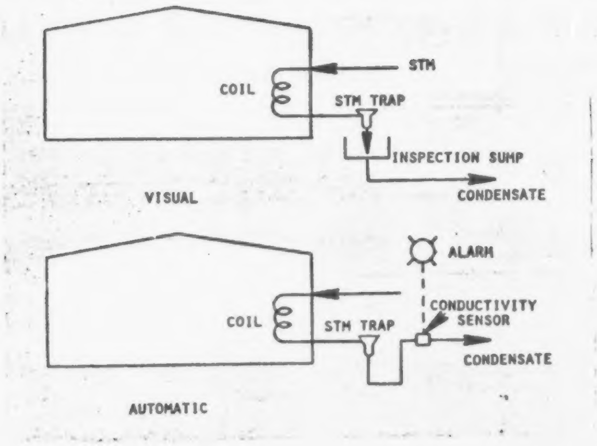

STM
COIL
STM TRAP
INSPECTION SUMP
CONDENSATE
VISUAL
ALARM
CONDUCTIVITY
SENSOR
COIL
STM TRAP
CONDENSATE
AUTOMATIC

Figure 111. Internal heating coil monitoring system (168)

usually a simple task to dig a small pit or construct temporary dikes around the tank.

- The condition of foundation and supports of tanks should be assessed regularly.

  In order to allow for adequate inspections and possible structural calculations, up-to-date drawings of the tank, foundation and structure must be maintained. Records of inspection should be kept for future reference.

- If a tank has internal heating coils, the condensate from these coils must be monitored for oil content.

  Condensate oil content can be monitored visually or automatically. Figure 111 depicts the visual method using an inspection sump and the automatic method using a conductivity probe.

- Condensate from heating coils should be directed to oil/water separator or similar systems.

- Heating coils should be tested, maintained and replaced as needed.

- External heating systems are preferable to internal heating coils.

  Typical external systems use plate coils which are placed on the outside of the tank near the bottom. Plate coils are bolted together and equipped with a band that can apply pressure to the contact surface between tank and coil for improved heat transfer.

- Internal condition of tank should be checked during every clean out maintenance.

Overfilling of storage tanks is a frequent cause of accidental spills. Preventative engineering techniques are listed below:

- Tanks should be carefully gauged before filling.

- High level alarms and pump shutoff devices should be in place.

  Figure 112 shows a control system that will automatically stop a tank from overfilling. The signal generated by the level alarm can be used to close the inlet valve, stop the pump or both.

- Overflow pipes connecting to adjacent tanks should be in place.

- Automatic gauges and fail-safe devices must be tested periodically.

- A communication system between pump operation and tank gauging operation should be available.

A number of preventive techniques are available with respect to storage tank rupture and boilover:

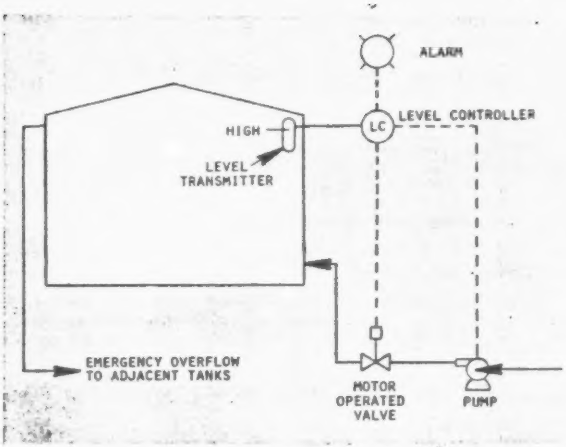

ALARM
LEVEL CONTROLLER
LC
HIGH
LEVEL TRANSMITTER
EMERGENCY OVERFLOW TO ADJACENT TANKS
MOTOR OPERATED VALVE
PUMP

Figure 112. Tank filling control system (168)

- Insure structural integrity by code construction.

- Relief valves for excessive pressure and vacuum should be in place.

  Many types of relief devices are possible. One of the most common is a pressure release manhole in the tank top which provides a large opening that can quickly relieve any pressure buildup.

- Safety relief provisions should be tested periodically.

- Adequate fire protection facilities must be available.

Even tank maintenance practices, such as tank cleaning and water drawoff, can generate material spillage and usually do. Pollution problems can be minimized by practicing the following guidelines.

- Water drawoff from crude storage should go to oil/water separator or oily sewer system.

- Water drawoff must be accomplished under controlled conditions with fail-safe devices, direct supervision, visual inspection, etc.

- Tank bottoms (sludge) during cleanout should be disposed of promptly.

- Temporary containment should be provided for bottom sludge.

Underground pipes, valves, and fittings have a high leak potential due to their susceptibility to corrosion. The following practices should be considered when installing and maintaining underground piping systems:

- Corrosion resistant pipe is preferable.
- Carbon steel pipe should be coated and wrapped (coal tar, asphalt, waxes, resins, fiberglass, asbestos, etc.).
- Cathodic protection system should be in place where surrounding soils contain organic or carbonaceous matter such as coke, cinders, coal, acid wastes, or other conditions. A soil resistivity survey may be in order.

  There are companies that specialize in cathodic systems and they provide routine inspection services.
- Corrosion inhibitors should be used in piped products where internal corrosion is found and the inhibitor is compatible with the product.
- Marking lines should be obvious to prevent damage by third party excavators.
- Block valves should be located at strategic locations and periodically checked for operability.
- Insure that pipe meets specifications codes.

- Pressure drop fail-close devices should be in place. If the pressure in a line changes, then alarms can be activated and shutdown procedures initiated.

- Check valves to insure one-way flow should be in place where required.

- Rate of flow indicators should be in use.

- Pipe corridors should be inspected visually.

- Pipe lines should be hydrostatically tested periodically.

- Accoustical or magnetic testing equipment should be used to check for leaks.

- Condition of pipe should be checked and recorded when construction activities expose buried lines.

- Inventory of emergency repair equipment and fittings should be maintained.

- All abandoned lines should be removed, plugged or capped.

Above-ground piping systems also exhibit potential for leakage. Proper preventative techniques are as follows:

- Frequent inspection should be made.

- Protection from vehicle collision should be used.

- Abrasion around pipe supports should be controlled.
- Pressure drop fail-close devices should be in place.
- Block valves should be installed at strategic locations.
- Rate of flow indicators should be in place.
- A preventive maintenance program should be in force.
- Inventory of emergency repair equipment and fittings should be maintained.
- All abandoned lines should be removed, plugged or capped.

If a storage area spill does occur, the spill should be contained by a system of dikes, which should surround each storage tank. Dikes must be constructed to accommodate the maximum expected spill volume. Adequate freeboard allowance for rainfall retention is imperative. Dikes should be stabilized with an impervious coating such as asphalt, clay, or concrete, so that leak potential is minimized. Material of construction should be of an erosion-resistant nature. With respect to maintenance, the following guidelines should be established as practice.

- A program of dike inspection and maintenance should be in force.

- Vegetation on earth dikes should be controlled.
- Through-the-dike pipes no longer in use should be removed or plugged.
- Breaches made in dikes for maintenance purposes should be minimized. Build ramps for vehicle access.

Even if the diking system is adequate and well maintained, overspills or leaks may occur due to a problem with the containment area drainage valve. The following general practices should be employed:

- Positive shutoff valves should be used, instead of the flapper type.
- Full operational range (positive open and closed) should be assured.
- Valves should be locked in closed position.
- Visual indicator should be installed in the drainage system
- Easy access to drainage valves should be maintained.
- All weather operation should be assured, and no debris should be present in the valve area.

When draining dikes of oily water or stormwater, the following guidelines should be practiced:

- Retained water should be checked for oil contamination before release.

- Contaminated waters should go to oily water sewer (oil/water separator system).

- Storm waters (uncontaminated) can be routed to the stormwater drain.

- Records of drainage operations should be kept.

Miscellaneous practices that do not fit into any one category are listed below:

- A closed drainage system should be installed at sample locations.

- A maintenance and housekeeping program for drainage ditches and sewer inlets should be followed.

- Flooding of separator facilities must be precluded by retention, designing separator for stormwater flow and installing connected spare pumping capacity. Such designs may be governed by NPDES regulations.

- Procedures for minimizing concentrated oil dumps to the separator (sample coolers, bleed valves, etc.) must be followed.

- Absorbents are preferable to flushing to sewer during maintenance of piping and equipment.

- Security should be observed through limited access lighting, fencing, patrols, alarms, etc.

- Overpressure release valves should be installed on all process vessels to prevent plant losses and subsequent material spills.

D-5.2 Material Spill Countermeasures

A material spill contingency plan indicates procedures to be followed in the event that a spill occurs. There are four phases to a material spill contingency plan: detection, containment, recovery, and disposal.

D-5.2.1 Detection

Suitable detection methods must be employed, so that a material spill, no matter how minor, can be detected quickly. Although large spills usually receive immediate attention, this may not be true with smaller spills, whether continuous or intermittent. Frequently, small spills go unnoticed and unreported unless suitable detection methods are used. Some methods lie midway between prevention and detection.

Periodic inspections are essential. A complete survey can identify potential problem areas for periodic or continuous surveillance. Target areas should include heavily eroded stream banks where pipeline crossings occur, points of pipeline exposure, and any area where construction or excavation work is in progress. Generally, observation methods are marginally effective, and companion methods should be employed.

Oil sensitive probes can be located throughout a drainage system of a potential spill. When a spill occurs, feedback to a central control panel will immediately identify the location. Two types of probes are predominant: a conductivity type which depends on an induced change in the dilectric constant, and an ultrasonic type which is triggered by a change in viscosity. These units will signal the presence of oil in an area but not the source location of the spill.

Tagging may be used to identify both the source of a leak and the spread. This consists of adding coded materials to the stored or piped materials and then periodically analyzing drainage samples for their presence. The materials used must satisfy the following criteria:

- Physically and chemically stable
- Readily identifiable
- No effect on commercial uses of material
- Soluble and dispersible in the material, yet insoluble and nondispersible in water
- Inexpensive

Examples of tagging substances include halogenated aromatics, nitrous oxide, and radiochemicals. Tagging has not been widely used because of cost and complicating factors.

D-5.2.2 Containment

In the event that storage tanks are undiked or a material spill extends beyond the diked area, diversion systems, such as a catchment basin containing an oil trap, should be available. These should be designed to contain at least the amount of stored material plus sufficient excess capacity to insure complete interception. The primary separation of oil from the water should be accomplished as early in the system as possible so that the problem of handling large volumes of oil/water mix is minimized.

Should a spill take place outside the confines of a drainage system, a temporary dike or diversion trench must be constructed. The location would depend on expected direction and rate of flow. Information concerning these two factors, and in particular their relationship to temperature, should be included in a reaction plan.

Materials and equipment necessary for the construction of diversion or holding structures should be on hand. Barriers may be manufactured or improvised from a wide variety of materials including wood, plastics and metal. In some cases, locally available materials such as hay bales and sandbags will suffice. Aside from the requirement for mechanical strength, other considerations would include susceptibility to heat in the event of a fire and softening or cracking in the presence of some mineral oil components. Equipment that should be available includes standard excavation machinery and tools and commercially marketed booms.

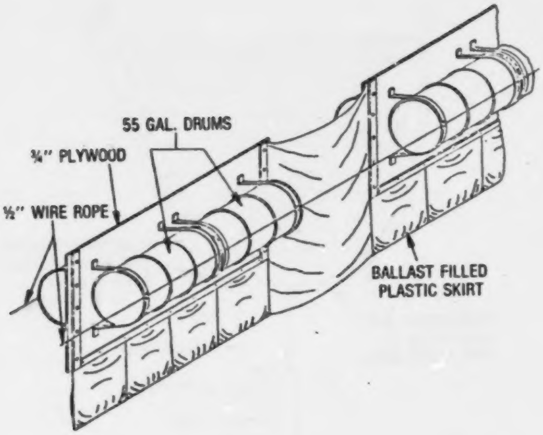

55 GAL. DRUMS
¾" PLYWOOD
½" WIRE ROPE
BALLAST FILLED PLASTIC SKIRT

Figure 113. "Navy" boom (169)

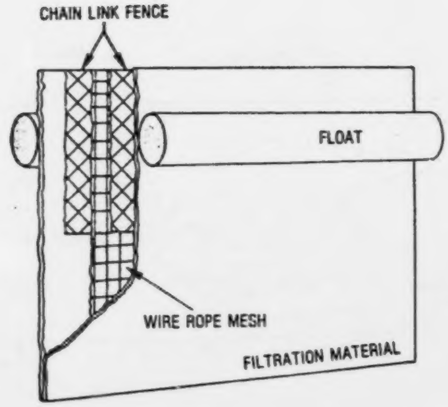

CHAIN LINK FENCE
FLOAT
WIRE ROPE MESH
FILTRATION MATERIAL

Figure 114. Kain boom (169)

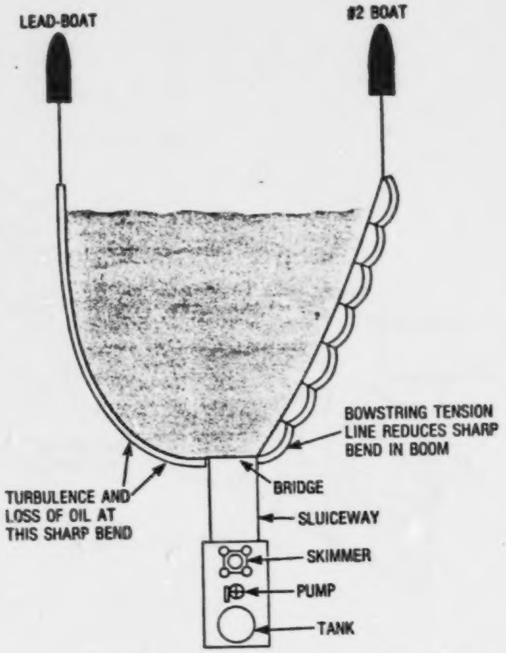

LEAD-BOAT
#2 BOAT
BOWSTRING TENSION LINE REDUCES SHARP BEND IN BOOM
TURBULENCE AND LOSS OF OIL AT THIS SHARP BEND
BRIDGE
SLUICEWAY
SKIMMER
PUMP
TANK

Figure 115. Boom/skimmer configuration for oil spill cleanup (169)

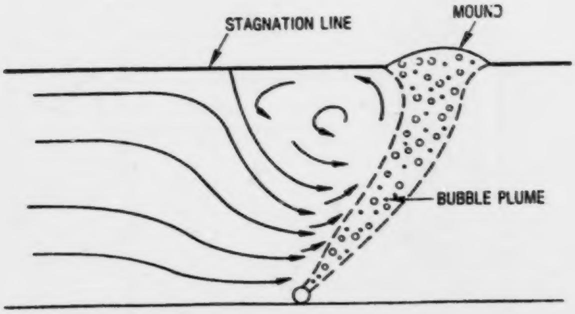

STAGNATION LINE
MOUND
BUBBLE PLUME

Figure 116. Circulation pattern upstream of an air barrier in a current (169)

Surface tension modifiers inhibit the spread of oil in water. When relatively small quantities of these chemicals are placed on the surface next to the floating oil, the oil is repulsed and tends to agglomerate. Application is simple; only a small amount need be used, applied as a coarse spray on the water at the edge of the spill. The effects last only a matter of hours, so cleanup plans should be implemented as soon as possible. As with any chemical, approval for the use of surface tension modifier must be obtained from appropriate governmental agencies.

D-5.2.3 Recovery

Numerous harvesting devices and various removal techniques exist for handling harbor and inland spills. Sorbents are oil spill scavengers, cleanup agents which adsorb and/or absorb oil. Based on origin, sorbents may be divided into three classes:

- Natural products include those derived from vegetative sources such as straw, seaweed and sawdust; mineral sources such as clays, vermiculite and asbestos; and animal sources such as wool wastes, feathers and textile wastes.

- Modified natural products include expanded perlite, charcoal, silicone-coated sawdust and surfactant-treated asbestos.

- Synthetic products include a vast array of rubber, foamed plastics, and polymers. Table 150 details the effectiveness of various materials.

TABLE 150. SORBENTS RELATIVE EFFECTIVENESS AND COSTS (169)

Type material	Pick-up ratio-weight oil pick-up/weight absorbent	Unit cost absorbent ($/T absorbent)	$ cost of absorbent for cleanup of 1,000-gal. oil spill*
Ground pine bark, undried	0.9	6	27
Ground pine bark, dried	1.3	15	47
Ground pine bark	3		
Sawdust, dried	1.2[a]	15	50
Industrial sawdust		56	
Reclaimed paper fibers, dried, surface treated	1.7	30	75
Fibrous, sawdust and other	3		
Porous peat moss	1.0		
Ground corn cobs	5	30	21
Straw	3-5[b]	30	27
Chrome leather shavings	10	indicated comparable to straw in cost.	
Asbestos, treated	4	500	440
Fibrous, perlite and other	5	416	290
Perlite, treated	2.5	230	320
Talcs, treated	2	70-120	120-210
Vermiculite, dried	2		
Fuller's earth		25	
Polyester plastic shavings	3.5-5.5	100	80
Nylon-polypropylene rayon	6-15		
Resin type	12	3,100	900
Polyurethane foam	70	20,000	1,000
Polyurethane foam	15	4,500	1,050
Polyurethane foam	70		
Polyurethane foam	40	2,260	195
Polyurethane foam	80	1,200	55

[a] Another reference gives a ratio of 20

[b] Other reports have indicated ratios of 20 and above

*1000 gal - 3785 liters

The requirements for a satisfactory sorbent include the following:

- Aids in handling and removing oil
- Minimizes spread of oil
- Is nontoxic
- Enhances performance of booms and other skimming devices

Removal of soil on water may require skimming. Skimmers may be purchased commercially or built for a particular application. Additionally, they may be floating, fixed, or mobile (mounted on boats, barges, trucks, etc.). The type of skimmer depends on its probable application. Of primary concern is its capacity in terms of total fluid handling volume, recovered oil volume, and pumping rate. These factors should be compatible with the expected utilization. Of secondary importance is the size, seaworthiness, speed, maneuverability, and other skimmer characteristics. Figure 117 shows the classes of skimmers.

Once the spill has been contained, it is usually removed and disposed of with a vacuum truck. One or more of these should be permanently assigned to the installation. If this is not the case, outside contractors must be identified and made familiar with the site facilities.

An underground water supply may be endangered by a land spill. A considerable portion of the oil can be removed by excavating the contaminated soil before the oil has reached great depths. The extent or depth to which this would be

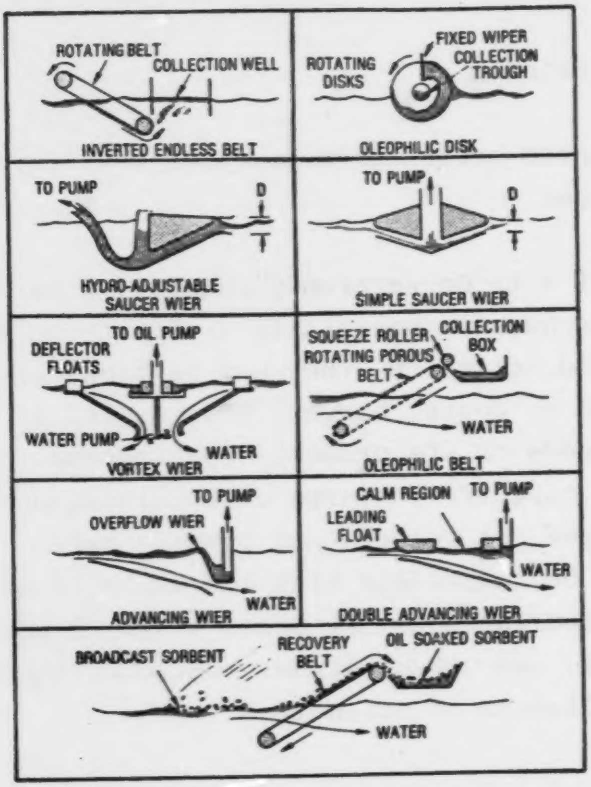

ROTATING BELT
COLLECTION WELL
INVERTED ENDLESS BELT
FIXED WIPER
ROTATING DISKS
COLLECTION TROUGH
OLEOPHILIC DISK
TO PUMP
D
HYDRO-ADJUSTABLE SAUCER WIER
TO PUMP
D
SIMPLE SAUCER WIER
TO OIL PUMP
DEFLECTOR FLOATS
WATER PUMP
WATER
VORTEX WIER
SQUEEZE ROLLER
COLLECTION BOX
ROTATING POROUS BELT
WATER
OLEOPHILIC BELT
TO PUMP
OVERFLOW WIER
WATER
ADVANCING WIER
CALM REGION
TO PUMP
LEADING FLOAT
WATER
DOUBLE ADVANCING WIER
BROADCAST SORBENT
RECOVERY BELT
OIL SOAKED SORBENT
WATER

Figure 117. Classes of skimmers (169)

economically feasible is a function of the type of oil as well as the underlying soil structure.

Oil from a land spill may reach the water table. If its viscosity is not too high, large amounts may be recovered by pumping. A well is drilled, centered in the spill, and screened at a depth no further than the oil/groundwater interface. In the pumping process, a cone of depression of the oil/water interface will be formed and will prevent oil from spreading further. At first the pump should extract oil exclusively; it should extract progressively more and more water. The amount of pumping is a function of recovered oil, spilled oil, and oil retained by the soil. Generally, pumping should stop when the oil/water ratio becomes less than 1 percent.

Spills eventually reach the plant drainage system; therefore, the site treatment facilities play a significant role in the oil removal process. Various types of separators are in use. Besides the classical API type, there are gravity plate separators and a host of multistage separators, some equipped with coalescence filters. In addition, there are other devices that employ proprietary methods ranging from ultrasonic treatment to polyelectrolyte injection.

Separation is ideally followed by physical-chemical treatment. This will incorporate some sequence of coagulation, flocculation, sedimentation and possibly air flotation. The remaining petroleum fraction can be removed by biological treatment. The activated sludge process is commonly used, often in conjunction with an aerated lagoon and a trickling filter. Following a dewatering step, the sludge may either be incinerated or hauled off for landfilling operations by a local contractor.

D-5.2.4 Disposal

Slop oil which has been recovered prior to reaching the drainage system or which has been separated in the initial step of the treatment system can be disposed of in several ways:

- Recycling recovered oil back into the plant process is the most common and the most economical. This is done by bleeding the slop oil into the feedstock over a period of time. Any impurities picked up during recovery of the spill are removed along with the usual bulk, sediment, and water. Any emulsions which have been formed can be broken using chemical agents and heat. As long as extensive "weathering" (evaporation of volatile components) has not significantly affected the fuel quality, this method can be used.

- Reclaiming recovered oil for other uses is a less desirable alternative. It is economically feasible only when the oil is not amenable to blending with the feedstock. This is normally done by an outside contractor equipped with appropriate re-refining facilities. These might include steaming, filtering, and additive rebalancing. Such contractors frequently specialize in storage tank and sump cleanout operations as well.

- Burning is another method of final disposal of oil, particularly nonreclaimable sludges. Large amounts can efficiently be disposed of in this manner with the help of combustion agents or by blending with lighter grades of fuel such as kerosine. The mixture is then atomized and burned. This course of action requires careful control to obtain complete combustion to avoid air pollution.

- Dispersing. Dispersants are chemical agents which emulsify or solubilize oil in water. Their use is governed by Annex X of the National Contingency Plan. They should not be employed except when other methods are inadequate or infeasible.

- Sinking. As oil weathers and becomes more dense, there is a natural tendency of the residual fraction to sink. This phenomenon depends, of course, on the type of oil involved in the spill. Oil can be made to sink by application of a nucleus of high density material having an affinity for the oil (oleophilic property) and not having an affinity for water (hydrophobic property). The resulting mass of material then settles to the bottom. Typical oil sinking agents include sand, fly ash, lime, stucco, cement, volcanic ash, chalk, crushed stone, and specially produced materials such as carbonized-silicanized-waxed sands. These are effective on thick, heavy, and weathered oil slicks.

  The major problem in sinking oil is that the bonding of the agent with the oil must be nearly permanent. Many agents will release oil back into the environment after a period of time or as a result of agitation and turbulence. Microbial action on the oil-soaked particles also produces gaseous by-products which give the particle a tendency to float.

D-5.3 Fugitive Emissions Control

Hydrocarbon vapors and particulate matter are released to the atmosphere from storage tanks or piles and leaks from pipe and process vessels flanges. Emissions from storage tanks are due to several mechanisms that occur simultaneously as the tanks become warmer. The vapor within the tank expands and is released to the atmosphere, carrying hydrocarbons with it. The higher temperature also raises the equilibrium partial pressure of the hydrocarbons. In an effort to maintain equilibrium, more hydrocarbons are evaporated from the vapor phase. These evaporated hydrocarbons displace some of the vapor phase, causing further venting. Vent emissions from storage tanks can be controlled by the following practices:

- Eliminating the vent and building a tank which is strong enough to withstand the expected pressure
- Installation of a floating roof, thereby minimizing the vapor phase and allowing for changes in the volume of the stored hydrocarbons with temperature
- Passing the vented hydrocarbons through a control unit such as an adsorber.

These control methods can not only recover valuable hydrocarbons for use or for sale. They also decrease the hazard associated with the handling and storage of these materials. Moreover, in many cases, they improve the working conditions for operating personnel.

Leaks from pipe systems and process vessel flanges will occur and present yet another source of fugitive emissions.

Guidelines for the prevention of fugitive emissions from piping systems and process vessels are listed below:

- Tighten all flanges
- Replace leak-prone threaded couplings with flanges or welded joints
- Gasket materials and pump seals should be corrosion resistant and compatible with the process fluid
- Double sealed or canned pumps should be employed
- Rupture disks should be installed under relief valves, to avoid leaks if a valve reseats improperly
- Preventative maintenance and inspection programs for above-ground and buried pipelines should be set up. These procedures are similar to those discussed under material spill control
- Double-pipeline systems for leaks monitoring of buried pipelines should be considered
- The number of flanges, valves, and pumps should be minimized while provisions for promt isolation of leaking sections and disposition of their contents must be planned with great care
- Prior to maintenance work or routine disassembly, material scavenging systems should be used, such as evacuating a process vessel using a compressor or purging the vessel with an inert gas.

Fugitive dusts from coal, sulfur and SRC storage will generally be of a highly variable nature, depending on environmental conditions. Particle sizes are generally in the 1 to 100 micron range (169). For relatively small storage piles, such as sulfur storage, enclosures with particulate control apparatus must be weighted against outside storage piles using organic polymer coatings for dust control. For larger storage piles, such as the raw coal pile, enclosure is infeasible.

APPENDIX E - Baseline Factors for SRC-II Development

E-1 Planning and Design Factors

To a large extent, the planning effort conducted before the construction and operation of a commercial synfuels facility will greatly influence the magnitude of impacts. The development of acceptable and viable coal liquefaction technologies will entail the application of effective planning and design programs, from conceptualization to commercialization, during a period of 15 to 20 years. The scope, pace, and objectives of such activities will be influenced by the evolving national energy plans that combine initiatives to increase domestic energy supply, decrease domestic energy demand, and provide emergency preparedness measures (138).

Implicit to these efforts will be the development of research programs that will provide the following items:

- The location of alternative sites distributed geographically in the national interest.
- Technical information needed to verify plant design, establish precise operating procedures and plant reliability and the cost-effectiveness of emissions control technology.
- Environmental and industrial hygiene information needed to support and improve plant siting and design, assess impacts on the physical, biological and socioeconomic environments, and to prepare an overall synfuels development plan that is coordinated with the land use, transportation, and

other plans of local and state agencies. The development plan should specify criteria for preventing adverse environmental impacts on air, water, and land during the construction and operation of the facility, and set forth the appropriate ecological and health effects monitoring and surveillance programs that would extend from the preconstruction through the construction stages and the operational and post-operational stages (e.g., for at least 40 years). Also desirable would be the development of procedures at an early date for state and county inputs into specific project decisions (138).

E-2 Government Rulemaking Factors - Environmental Requirements

Following closely upon the recent enactment of the Toxic Substances Control Act (TSCA), the Resource Conservation and Recovery Act, and the 1977 amendments to the Clean Air and the Clean Water Acts, representatives of major industrial groups (petroleum, power, transportation and chemicals), have expressed much concern over several items that they perceive as a threat to their economic well-being (138); these issues are discussed here because of their relevance to an emerging synthetic fuels industry. The issues are as follows:

- Existence of an apparent "dollar crunch" to cover the cost of applying the best environmental control measures by the affected industries (138).

- An apparent consensus that existing environmental regulations are arbitrary and have been promulgated without sufficient federal research to ascertain their cost-effectiveness (138).

- The belief that the existing regulatory philosophy is based mainly on technological feasibility, with little or no regard to environmental need or benefit; this approach is perceived by some as wasteful in the control of toxic substances, in that the technologies for achieving new regulatory standards have yet to be fully demonstrated (138).

- The opinion that blind adherence to the zero-risk concept is inconsistent with governmental legislation and regulatory control in other areas such as auto traffic safety, radiation exposure and quality control for manufactured products (136).

- The new amendments to the Clean Air Act will cause licensing delays, increase the cost of building and operating power plants, reduce the number of suitable sites for building new power plants, lead to the loss of economics of scale by forcing construction of smaller plants, and generally limit industrial growth (138).

- The TSCA chemical inventory reporting requirements will increase the manpower needs of power plants through the requirement that by-products sold or used at levels greater than 45 Mg (100,000 pounds) per site requires the filing of comprehensive reports because, under TSCA, such outputs would make it necessary to classify the power plant as a manufacturer of chemical substances (138).

- The Clean Water Act requires industrial discharges, because of the stringent technology-based water quality requirements, to meet these standards while oftentimes ignoring the fact that municipal discharges and nonpoint stormwater discharges continue to pollute the waters (138).

- The opinion that improved mechanisms are needed to provide additional opportunities for industry groups to interface with regulatory agencies, particularly during the early stages of the rule-making process and prior to the publication of new regulations in the Federal Register (136).

- The consensus that the federal government should require long range planning for the construction of energy facilities, consider all relevant socio-economic factors, and provide for full citizen participation in the decision making process. In addition, it was recommended that EPA should promulgate new ambient air quality standards as soon as significant risks of harm to the health of the general population are established (138).

One rather interesting aspect of these concerns voiced by the industrial sector has been the recognition by President Carter that the 1977 amendments to the Clean Air and Clean Water Acts will have economic and resource impacts of their own, and that these impacts will require close analysis. The extent to which these factors will likely affect the U.S. Department of Energy Alternate Fuels Demonstration (AFDP) Program for a synthetic fuels technology cannot be fully assessed at this time. However, the proposed AFDP reportedly includes provisions for conducting performance tests on various types of environmental control equipment, on the premise that the best available technology will be identified for use by the synthetic fuels industry (AFDP). Whatever the outcome, the Congress has passed laws that are perceived as capable of protecting environmental quality. The DOE position on the impacts of existing regulations and standards is to give a higher priority to research directed towards producing cost-effective control technologies than to the determination of the impacts of alternative levels of control. In the final analysis, however, commercialization of any synfuels technology will largely be controlled by the extent to which national standards and criteria can be met (138).

E-3 Source Factors and Their Interactions

Discussions of pollutant releases and characteristics for nonpoint and point sources during the construction and operation phases of SRC liquefaction system and likely interactions between SRC source factors and the various abiotic and biotic features of a hypothetical site in White County, Illinois were addressed given in a previous report (47). Beyond these data, it appears fruitful to discuss the influence of variations in the operating parameters of an SRC facility on pollutants and their characteristic effects in by-product and product streams. For example, the rank and origin of the coal feed may influence the yield, distribution, and compositon of the product as well as the composition of waste streams (63). The kinds and quantities of trace elements in coal can act either to inhibit the liquefaction catalysts, or to act as catalysts themselves (43). At the relatively low reactor temperatures of the SRC process (less than 500°C) the chemical composition of the coal tar pitches varies widely with the nature of the coal feed, the temperatures, program, residence time, and the maximum temperature (43).

A major concern with regard to the effect of temperature on the production of carcinogenic agents in the SRC process is that the amount of these agents in coal tar pitches produced at less than 450°C, was reportedly very small while at temperatures between 450° and 560°C the amount of known or suspected carcinogens (primarily polynuclear aromatic hydrocarbons) increased markedly (43). Table 151 summarizes the general effects of using higher versus lower temperatures for coal conversion processes. Additional research will be required to resolve these and related problems associated with the SRC liquefaction process.

TABLE 151. EFFECTS OBSERVED FOR TEMPERATURE VARIATIONS USED DURING FOSSIL FUEL PROCESSING OR CONVERSION

	Quantities Observed With High Process Temperature (<500°C)	Quantities Observed With Low Process Temperature (<500°C)
Aromatics	greater	less
PAHs	greater	less
Carcinogens	greater	less
Cancer rate among coke plant workers	greater	less

Another point relating to the temperature factor is that of the boiling point of various fractions of the SRC product. For example, laboratory studies show that the carcinogenic potential of oil fractions having boiling points above 260°C is greater than that for oil fractions with boiling points below 260°C (43). However, it has been reported that SRC liquefaction oils will be less carcinogenic than coal tars, but likely more hazardous than petroleum crude (43).

E-4 Dissipative Forces

Contaminant dissipation in abiotic environments is one of the least explored ecological subjects, yet it has a great deal to do with the ability of people and entire ecosystems to resist or to recover from exposure to pollutants; this fact stems from the principle that the eventual effect of a contaminant is largely determined by the duration and level (or dose) of the exposure. However, strict confirmation of the dose-response concept has not been made at the ecosystem level (43). Suffice to say that physical dissipative forces act to establish the physical half-life of many organic contaminants in air, water, and soils.

Another aspect of the role of physical dissipative forces is seen in the ability of mobile organisms (including man) to detect the presence of ambient contaminants and then move away to areas of lower stress. Immobile organisms often respond to contaminants by sharply curtailing their rate of filtration or feeding activities (43).

The operation of these forces leads to the establishment of the biological half-life of many inorganic and organic contaminants in various media.

The most striking biological dissipative forces at the level of the organism include:

- Species-specific control of the permeability of cell membranes and tissues, thereby securing a slow or rapid absorption rate irrespective of dose.

- Storage of potentially toxic chemicals in fat, bone, and protein depots.

- Metabolic detoxification (i.e., degradation) of organic contaminants, converting them either to innocuous forms or to forms more toxic than the parent substance. Passage of degradation compounds across a food web can produce serious effects on higher life forms.

At the ecosystem level, the forces of physical dissipation and biological degradation provide the chief resistance mechanisms. Stress on ecosystems occurs in two forms, acute and chronic. In a chronically stressed ecosystem, the inference is usually made that losses of a given organic contaminant are partially offset by a continued fresh input. Under these conditions, the most sensitive species may be decimated or lost, but if sufficient species diversity exists, there can be restructuring of the ecosystem over a period of time. Adaptation normally is greatest among the microflora and insects having short generation times. Some evidence suggests that continued exposure to certain contaminants can induce an enhanced capacity for biodegradation at many, and perhaps all levels of the ecosystem (43).

With reference to acute ecosystem stresses, periodic acute contamination stresses may provide the greatest probabibility of damage. Sudden losses of key (or sensitive) species could trigger extensive ecosystems changes; this condition is particularly important for airborne contaminants. Large quantities of all volatile organic contaminants and many aerosols can be transported for long distances, transformed oxidatively in the atmosphere, and then deposited on vegetation and surface waters, sometimes with destructive effects (171). The problem of assessing the risks associated with the development of a synfuels technology will require the delineation of the reversible from the irreversible effects on ecosystems and on human populations (171).

E-5 Development and End Impacts

The socioeconomic impacts resulting directly from the construction and operation of a synfuels industry are termed development impacts; those resulting from the interplay between the primary development impacts (e.g., land area required by the plant and conjunctive developments, or the workforce) are termed end impacts. As pointed out elsewhere, because the potential end impacts could be almost as varied as that of existing local communities (e.g., highly site specific), it is generally more instructive to "match" the development impacts of synfuels industry with the existing features of selected illustrative impact communities (171). In turn, these results can be compared with data from a so-called average U.S. county, as shown in Table 152. The comparison of predicted operating and maintenance costs versus existing local expenditures reveals that differences in perceived public service needs between the population associated with the synfuels plant and the native (original) population, could produce political conflicts regarding the scale and the type of budgetary allocations, tax assessments, and the already established loyalties between the citizens and public officials (171). Further details on these and related comparisons are found elsewhere (171).

The importance of the analysis of end impacts by use of comparisons between impact communities and an "average" U.S. county situation is that it serves to flag needed policy decisions and actions that, if taken early, could greatly

TABLE 152. END IMPACTS ASSOCIATED WITH A HIGH-BTU GASIFICATION PLANT (138)

Factor (a)	Plant Development Impacts (b)	Illustrative Impact Communities					Average U.S. County
		A	B	C	D	E	
TOTAL EMPLOYMENT	4,240(c) 1,610	1,690	4,470	4,800	15,200	26,100	24,550
CRAFTSMEN, FOREMEN, OPERATIVES	2,640(c) 390	140	850	2,070	5,370	11,350	7,710
MALE EMPLOYMENT							
Total	1,130	1,340	2,750	3,610	9,850	17,010	15,270
Average Earnings (Dollars)	12,200	6,300	10,000	13,200	11,000	9,200	11,200
Employment Rate	-	96%	88%	93%	75%	83%	85%
FEMALE EMPLOYMENT							
Total	480	360	1,720	1,200	5,310	9,130	9,280
Average Earnings (Dollars)	9,400	3,700	4,100	4,400	4,100	4,600	5,300
Employment Rate	-	29%	53%	36%	37%	42%	49%
PRIMARY EMPLOYMENT							
Agriculture	-	960	610	600	380	1,720	910
Mining	700	10	50	1,320	2,250	1,330	200
Manufacturing	-	0	120	150	1,430	7,260	6,360
POPULATION							
Urban	3,350	0	9,020	7,190	25,310	16,500	47,890
Rural	-	4,900	3,150	5,770	27,200	59,500	17,280
Total	3,350	4,900	12,170	12,960	52,510	76,000	65,170
MIGRATION RATE							
During 1960's	-	-35%	-17%	+101%	-26%	-7%	-
During Early 1970's	-	-10%	-2%	-37%	+28%	0%	-
CITIES AND TOWNS (Number)							
2,500-5,000 Population	-	0	0	0	1	1	0.6
5,000-10,000 Population	-	0	1	1	0	2	0.5
10,000 and Over Population	-	0	0	0	1	0	0.6
POPULATION AGE GROUPS							
Ages 5-17	960	1,660	3,540	3,770	18,430	19,080	16,830
Ages 18-39	1,360	970	2,820	4,170	13,760	18,170	8,760
Ages 65 and Over	110	410	1,550	620	2,570	9,280	6,450
OTHER DEMOGRAPHIC GROUPS							
Non-White	-	410	100	120	18,960	150	8,170
Nonstandard Households	1,450(c) 240	310	1,280	810	4,500	6,580	6,230
HOUSEHOLD INCOME							
Total (Million Dollars)	22	15	50	67	170	273	300
Per Capita (Dollars)	6,500	3,010	4,120	5,190	3,230	3,590	4,610
HOUSING STOCK							
Single-Family Units	680	1,400	3,130	1,790	11,520	19,770	15,060
Mobile Home	280	90	260	1,670	1,590	1,270	590
Multi-Family Units	170	80	920	490	1,640	4,400	6,050
Total	1,130	1,570	4,310	3,950	14,750	25,440	21,700
Adjusted Total	-	0	3,100	3,150	7,550	5,530	15,070

(continued)

TABLE 152. (continued)

Factor (a)	Plant Development Impacts (b)	Illustrative Impact Communities					Average U.S. County
		A	B	C	D	E	
LAND REQUIREMENTS							
Plant and Community Development (Acres)	821	821	821	821	821	821	821
Extraction Land (Acres) (e)	(d)	5,500	1,600	1,600	7,100	4,800	(d)
Total (Square Miles) (f)	(d)	9.9	3.8	3.8	12.4	8.8	(d)
LAND SUPPLY (Square Miles)							
1% Total Land Area	-	20	40	50	55		12
Gently Sloping Land	-	1,100	1,310	2,380	3,580	380	-
Federal Administration Land	-	500	1,110	890	4,810	0	-
LAND VALUE (Thousand Dollars)							
As Farmland	-	800	180	140	310	2,400	-
Market Value Farm Production	-	120	30	20	40	280	-
COMMUNITY DEVELOPMENT COSTS VERSUS LOCAL DEBT OUTSTANDING							
Total (Thousand Dollars)	16,090	490	1,680	6,700	6,250	20,760	19,230
Per Capita (Dollars)	3,540	100	140	520	120	270	300
OPERATION AND MAINTENANCE COSTS VERSUS CURRENT LOCAL EXPENDITURES							
Total (Thousand Dollars)	2,000	1,560	4,240	8,940	18,070	25,400	25,744
Per Capita (Dollars)	600	380	350	690	340	330	400
LOCAL TAXING DISTRICTS (Number)	-	16	19	4	12	62	21
MUNICIPALITIES (Number)	-	4	2	1	3	25	6

(a) All costs and revenues are expressed in 1975 dollars.

(b) All values are for the operational phase except as noted.

(c) Peak construction.

(d) Varies by coal region.

(e) Land required over 20 years

(f) Sum of plant, community development and mining land.

temper the predicted impacts. For example, early community action prior to the time that a synfuels technology becomes operational could (138):

- Report the potential for friction among racial, ethnic, age, or income groups in the impact community.
- Reduce the front-end financing problems of local government.
- Increase job opportunities for various groups of local residents.
- Assist planning for the transition to a post - synfuels situation after the plants are closed down.
- Assist local business and financial groups to respond to housing and secondary employment needs.
- Enhance the beneficial effects of the synfuels development on the existing local infrastructure.
- Improve the coordination responses of state, local, and federal agencies in meeting the problems of synfuels development.

E-6 Standards Applicable to SRC Development

E-6.1 State Emission Standards

The following tables are a summary of selected state emission standards (organized according to EPA region)

TABLE 153. PENNSYLVANIA STANDARDS FOR CONTAMINANTS

Particulates - unspecified process

For effluent gas discharge rates greater than 8500 dscm/min, 458 mg/dscm is allowed.

Particulates - petroleum refineries

20 kg/metric ton of liquid feed

Visible Emissions - unspecified process

Opacity equal to or greater than 20% is not allowed for aggregate periods of more than three minutes in any hour. Additionally, 60% opacity may never be exceeded. Opacity due to uncombined water mists is excluded in determining opacity levels.

TABLE 154. APPLICABLE AIR POLLUTION REGULATIONS IN WEST VIRGINIA

Coal Preparation

Drying and Handling

Particulates - for volumetric flow rates greater than 6800 scm/min., the allowable emission rate is 0.16 g/scm.

Air Table Operation

Particulates - 0.11 g/scm

Manufacturing Process Operations

Particulates - for process weight rates exceeding 45,500 kg/hr the allowable emission rate is 9.6 kg/hr.

Smoke - no smoke darker than No. 1 on the Ringlemann Smoke Chart is permitted. No smoke darker than No. 2 on the Ringlemann Smoke Chart is permitted for more than five minutes in any sixty minute period.

TABLE 155. STANDARDS OF PERFORMANCE FOR PETROLEUM REFINERIES IN KENTUCKY

Particulates

1.0 kg/metric ton feed

Carbon monoxide

0.050% by volume

Sulfur dioxide

Emissions may not exceed the equivalent of combustion of fuel gas containing 230 mg/dscm of hydrogen sulfide.

TABLE 156. APPLICABLE ILLINOIS EMISSIONS REGULATIONS

New Fuel Combustion Emission Sources

Sulfur Dioxide

For actual heat input ≥ 264 x 10^6 kJ/hr resulting from the burning of solid fuel exclusively, SO_2 emissions must be exceed 0.5 kg/million kJ.

Nitrogen Oxide

For actual heat input ≥ 264 x 10^6 kJ/hr resulting from the burning of solid fuel exclusively, NO emissins must not exceed 0.3 kg/10^6 kJ.

Carbon Monoxide

For actual heat input ≥ 10 M Btu/hr, CO emissions must not exceed 200 ppm corrected to 50 percent excess air.

Fugitive Particulate Matter

Emissions should not exceed 0.043 kg/10^6 kJ actual heat input using solid fuel exclusively over a period of one hour.

(continued)

TABLE 156. (continued)

Particulates

Discharge of particulates from new process sources during a one hour period shall not exceed the allowable emission rates specified by the following equations:

Process weight rate < 450 tons/hr

$$E = 2.54\ (P)^{0.534}$$

Process weight rate ≥ 450 tons/hr

$$E = 24.8\ (P)^{0.16}$$

where

E = allowable emission rate in pounds/hour

P = process weight rate in tons/hour

Waste Gas Disposal

Organics

Emissions from any petroleum or petrochemical manufacturing process should not exceed 100 ppm equivalent methane.

TABLE 157. NEW MEXICO EMISSIONS STANDARDS FOR COMMERCIAL GASIFIERS

Constituent/Operation	Standard	Remarks
Particulates		
Briquetting	69 mg/scm	Based on heat input to boiler
General operations	69 mg/scm	
Gas burning boiler	0.013 kg/10^6 kJ	

(continued)

TABLE 157. (continued)

Constituent/Operation	Standard	Remarks
Hydrogen sulfide Carbon disulfide Carbon oxysulfide (Any combination)		
General operations	100 ppm (total) 14 mg/m^3 (hydrogen sulfide)	
Hydrogen cyanide		
General operations	11 mg/m^3	
Hydrogen chloride		
General operations	7.4 mg/m^3	
Ammonia		
General operations Storage	17.4 mg/m^3	
Sulfur dioxide		
Gas burning boilers	0.07 $kg/10^6$ kJ	Based on heat input to boiler
Sulfur		
General operations	0.003 $kg/10^6$ kJ	Based on heat input to feed

Hydrocarbons

Storage - for a vapor pressure greater than 0.1055 kg/cm^2 a floating roof, vapor recovery and disposal system or equivalent control technology is required.

Loading systems - vapor collection adapters are required.

TABLE 158. NEW MEXICO EMISSIONS STANDARDS FOR REFINERIES

Constituent	Concentration (Metric)	Remarks
Mercaptan	0.11 kg/hr	New facilities
Carbon monoxide	573 mg/m^3 22,900 mg/m^3	Existing facilities

TABLE 159. TEXAS EMISSIONS LIMITS FOR FOSSIL FUEL BURNING STEAM GENERATORS

Constituent	Concentration	Remarks
Particulates	0.13 kg/10^6 kJ 0.04 kg/10^6 kJ	24 hr max (2) 2 hr max (3)
Suflur dioxide	1.3 kg/10^6 kJ	
Nitrogen oxides	0.30 kg/10^6 kJ 0.21 kg/10^6 kJ 0.11 kg/10^6 kJ	2 hr max (4) 2 hr max 2 hr max

(1) applicable for heat inputs greaters than 2640 x 10^6 kJ/hr.

(2) solid fuel burners

(3) gas and liquid fuel burners

(4) standards apply to opposed fire, front fired, tangential fired-steam generators, respectively.

TABLE 160. STANDARDS OF PERFORMANCE FOR PETROLEUM REFINERIES IN COLORADO

Particulates

1 kg/metric ton

30% opacity for greater than 3 minutes in any hour is not allowed. Failure to comply due to uncombined water is not a violation.

Carbon Monoxide

Discharge gases may not contain greater than 0.050% carbon monoxide by volume.

Sulfur Dioxide

Emissions may not exceed those resulting from fuel gas containing 230 mg/dscm of hydrogen sulfide.

TABLE 161. SELECTED SOUTH DAKOTA INDUSTRIAL EMISSIONS STANDARDS

Fuel Burning Installations

Particulates

0.13 kg/10^6 kJ of heat input

Sulfur Oxides

1.3 kg/10^6 kJ of heat input

Nitrogen Oxides

0.09 kg/10^6 kJ of heat input

General Process Industries

Particulates

$E = 55.0\ P^{0.11} - 40$

where E = rate of emission in lb/hr
P = process weight rate in ton/hr

TABLE 162. APPLICABLE WYOMING EMISSIONS REGULATIONS

New Fuel Burning Equipment - Sulfur Dioxide

$0.09 \text{ kg}/10^6 \text{ kJ}$ input (applicable to coal burners)

New Fuel Burning Equipment - Nitrogen Oxides

$0.30 \text{ kg}/10^6 \text{ kJ}$ input (applicable to nonlignite coal burners)

Stationary Sources - Carbon Monoxide Requirement

Stack gases shall be treated by direct flame after burner as required to prevent exceeding ambient standards.

Stationary Sources - Hydrogen Sulfide Requirement

Gases containing hydrogen sulfide shall be vented, incinerated, or flared as necessary to prevent exceeding ambient standards.

New Sources - Particulates

$E = 17.31\ P^{0.16}$ (for P 30 tons/hr)

where E = maximum allowable rate of emissions in lb/hr
P = process weight rate in tons/hr

For a 50,000 bbl/day SRC plant

$$E = 17.31 \; \frac{22{,}000 \text{ ton/day}}{(24 \text{ hr/day})} \quad 0.16$$

$$E = 17.31\ (917)^{0.16} = 51.6 \text{ lb/hr} = 23.4 \text{ kg/hr}$$

TABLE 163. ARIZONA AIR QUALITY GOALS

Constituent	Concentration	Remarks
Particulates	100 g/m^3	24 hr max.
Nonmethane hydrocarbons	80 g/m^3	3 hr max. (6-9 A.M.)
Carbon monoxide	7 mg/m^3	8 hr max.
Photochemical oxidants	80 g/m^3	1 hr max.

Standard Conditions:
Temperature = 16°C
Pressure = 1.03 kg/cm^2

TABLE 164. INDUSTRIAL EMISSIONS STANDARDS IN ARIZONA

Particulate Emissions - Process Industries - General

$E = 55.0\ p^{0.11}-40$ ($E = 17.31\ p^{0.16}$ for Phoenix-Tucson Air Quality Control Region)

where:

E = max. allowable emission rate (lb m/hr)
P = process weight rate (ton m/hr)

For commercial SRC plants:

$$E = 55.0 \quad \frac{20{,}000 \text{ ton/day}}{(24 \text{ hr/day})}\ ^{11}{}_{-40} = 75.2 \text{ lb m/hr} = 165.4 \text{ kg/hr}$$

$E = 17.31\ p^{0.16}$ = 50.8 lb m/hr = 111.9 kg/hr (Phoenix-Tucson)

Suflur - other industries

Requirement: a minimum of 90% removal

Storage of volatile organic compounds
(for storage capacities of 65,000 gallons or greater)

Requirement = A floating roof is required for compounds with vapor pressure greater than 2 lb/in^2 but less than 12 lb/in^2. Equipment of equal efficiency may be substituted. The pressure range in metric units is from 0.1406 kg/cm^2 to 0.8436 kg/cm^2.

TABLE 165. EMISSIONS STANDARDS FOR INDUSTRIAL PROCESSES AND FUEL BURNING EQUIPMENT IN ALASKA

Visible Emissions	20% opacity+
Particulate matter (coal burning equipment)	114.4 mg/m^3
Sulfur compounds (as SO_2)	1310 mg/m^3

+Denotes that the standard may not be exceeded for a total of more than three minutes in any hour.

potentially applicable to development or operation of SRC facilities.

E-6.2 Air Pollutants Associated with SRC

E-6.2.1 Regulated Pollutants of Concern and Suggestions for Environmental Goals Relative to SRC Systems

For the reasons discussed previously, the MEGs are probably the best suggestion for environmental goals. Adverse environmental effects which may become a problem when these concentrations are approached are found in Section 5 of this report.

E-6.2.1.1 Phenols

Because of its low volatility, phenol is primarily of concern as a water contaminant rather than an air contaminant. Only in the workplace does the potential air emission of phenol present any health or ecological concern. OSHA standards limit the workplace concentration of phenol to 19 mg/m^3.

In Fort Lewis pilot plant studies, essentially all air samples showed less than 0.04 ppm of phenol and less than 0.01 ppm of the three type of cresols. Xylenols, ethylphenols and other higher phenols were not detected (135).

The highest airborne phenol concentration detected is 0.03 mg/m^3 (0.008 ppm), which is about two orders of magnitude below the permissible occupational exposure level of 19 mg/m^3 (5 ppm) for phenol (135).

E-6.2.2 Alkanes, Alkenes and Aromatic Hydrocarbons

Emission limitation of hydrocarbons from SRC facilities would be imposed primarily through New Source Performance Standards. Hydrocarbons may be emitted to the atmosphere by incomplete combustion, leaks in hydrocarbon by-product transfer, evaporation from aqueous effluent of cooling streams during slurry mixing, or emission of flue gases from coal, char, and oil combustion.

Petroleum storage at refineries requires specified control technology, depending upon the vapor pressure of the hydrocarbons. Storage vessels must be equipped with either a floating roof or a vapor recovery system or equivalent. Similar controls could, foreseeably, be imposed on SRC product storage.

In addition to New Source Performance Standards, the National Ambient Air Quality Standards specify the maximum permissible atmospheric level of nonmethane hydrocarbons to be 0.16 mg/m^3. The enforeceability of such an ambient level standard has increased and will continue to increase with the implementation of the Clean Air Act. If nonmethane hydrocarbons were to be included in determining prevention of significant deterioration (PSD) increment limitations, then the building of coal liquefaction facilities in certain areas could conceivably be restricted on the basis of such ambient level regulations.

E-6.3 Summary of Most Stringent Water Quality Standards (118)

The following compilation represents the most stringent criteria as established by the individual states, regions, and countries considered for this project. It must be emphasized that this compilation represents an analysis based on numerical considerations only; compliance with these criteria should, in all probability, allow construction at any location. However, engineering design based on the following criteria may result in over design, and this should be considered for any cost data developed that are based on the criteria.

E-6.3.1 General Criteria for Receiving Waters

The following minimum water quality procedures should be applicable to all receiving waters, and such waters should be:

- Free from substances that will cause the formation of putrescent or objectionable sludge or bottom deposits.

- Free from floating debris or other floating materials. (Alternate: Free from floating debris or other floating materials in amounts to be unsightly or deleterious).

- Free from substances producing color, or odor to the water. (Alternate: Free from substances which produce color or odor in amounts to be deleterious or to such degree as to create a nuisance).

- Free from substances in amounts which would impart an unpalatable flavor to fish.

- Free from substances which would be harmful or toxic to human, animal, plant, or aquatic life.

(Alternate: Free from substances in amounts which would be harmful or toxic to human, animal, plant or aquatic life).

- Free from substances or conditions in concentrations which would produce undesirable aquatic life. (Alternate: Add to above, "Free from nutrients entering the waters in concentrations that create nuisance growths of aquatic weeds and algae").
- Free from toxic substances, heated liquids or any other deleterious substances attributable to sewage industrial wastes or other wastes. (Alternate: Add to above, in amounts which would affect public health or the desirability of the beneficial water use).

Acid mine drainage control measure applicable to coal processing include:

- Surface and ground water shall be diverted where practicable to prevent entry or reduce the flow into and through the mine workings.
- Refuse from the mining and processing of coal shall be handled and disposed of in a manner so as to minimize the discharge of acid mine drainage to streams.
- Discharge of acid mine drainage to streams shall be regulated to equalize the flow of daily accumulation throughout a 24 hour period.

E-6.3.2 Specific Water Quality Standards - Receiving Waters

The following table illustrates specific water quality criteria which should apply to all waters:

TABLE 166. SPECIFIC WATER QUALITY STANDARDS - RECEIVING WATERS

Substance to condition	Limitation
pH (range)	7.0-8.8 (Br. Columbia)
Temperature	1C° Rise (Canada-Federal) 60°F (Alaska-Washington) 85°F (North Dakota)
Dissolved oxygen	9.5 mg/l (fresh water) 7.0 mg/l (Marine water) 5.0 mg/l (Probable average)
Color	None 15 Color units (other criteria)
Turbidity	No increase 10 JTU* (Probable average)
Total coliform bacteria	50/100 ml
Fecal coliform bacteria	10/100 mg (Domestic water supply) 200/100 ml (Probable average)
Settleable solids	None (Essentially free) 200 mg/l - (Pennsylvania)
Dissolved solids	100 mg/l (Br. Col., fresh water)
Oil and grease	None 10 mg/l (Others)

*JTU = Jackson Turbidity Units.

(continued)

TABLE 167. (continued)

Constituent	Concentration
Arsenic	0.01 mg/1
Asbestos	Lowest practicable level (IJC*)
Barium	0.5 mg/1
Boron	1.0 mg/1
Cadmium	0.002 mg/1 (0.01 probable)
Chloride	100 mg/1 (250 probable avg.)
Chlorine, residual	0.002 mg/1 (proposed IJC) (Br. Col.: Below detectable limits)
Chromium (hexavalent)	0.05 mg/1
Coablt	1.0 mg/1
Copper	0.005 mg/1 (proposed IJC; 0.10 probable average)
Cyanide	0.005 mg/1
Fluoride	1.0 mg/1
H_2S, undissociated	0.002 mg/1 (proposed IJC)
Iron	0.3 mg/1
Lead	0.01 mg/1 (proposed IJC, Lake Superior; Ohio = 0.04)
Manganese	0.05 mg/1
Mercury	0.0002 mg/1 (proposed IJC)
Mercury in fish	0.0005 mg/kg wet weight (proposed IJC)
Nickel	0.025 mg/1 (proposed IJC)
Nitrates	10 mg/1
Phenols	0.001 mg/1

(continued)

*IJC = International Joint Commission of the United States and Canada.

TABLE 167. (continued)

Constituent	Concentration
Phosphorus	0.05 mg/l
PCB (polychlorinated biphenyl), total	0.00 mg/l
Selenium	0.005 mg/l (0.01 probable average)
Silver	0.0001 mg/l (proposed IJC; 0.05 probable average)
Sulfate	250 mg/l
Uranyl ion	5.0 mg/l
Zinc	0.03 mg/l (proposed IJC)

E-6.3.3 Effluent Standards

(When not specified differently by discharge permit). Except as otherwise noted, compliance with the numerical standards should be determined on the basis of 24-hour composite samples, and no contaminant shall exceed five times the numerical standards at any time or in any one sample. No effluents shall contain the following:

- Settleable solids
- Floating debris
- Visible oil, grease, scum, or sludge solids
- Obvious color, odor and/or turbidity
- Fecal coliforms, concentration greater than 400/100 ml.

The following table lists concentrations of contaminants which should not be exceeded in any effluent.

TABLE 168. CONTAMINANTS AND CONCENTRATIONS NOT TO BE EXCEEDED IN ANY EFFLUENT

Constituent	Concentration
Aluminum	0.2 mg/1 (Br. Columbia, one industry category)
Ammonia	0.5 mg/1 (Br. Columbia, tentative)
Antimony	0.05 mg/1 (Br. Columbia, one industry category)
Arsenic	0.05 mg/1
Barium	1.0 mg/1
Boron	1.0 mg/1
Cadmium	0.005 mg/1 (Br. Columbia)
Chlorate	50 mg/1 (Br. Columbia, one industry category)
Chlorides	250 mg/1
Chlorine, residual	0.2 mg/1 (Br. Columbia, one industry category)
Chromium (hexavalent)	0.05 mg/1
Cobalt	0.1 mg/1 (Br. Columbia, one industry category)
Copper	0.05 mg/1 (Br. Columbia)
Cyanide	0.02 mg/1
Fluoride	1.0 mg/1
Iron	0.3 mg/1
Lead	0.05 mg/1 (Br. Columbia)

(continued)

TABLE 168. (continued)

Constituent	Concentration
Magnesium	150. mg/l (Br. Columbia, for fresh water; one industry category)
Manganese	0.05 mg/l (Br. Columbia)
Mercury	0.001 mg/l (Br. Columbia, tentative)
Molybdenum	0.50 mg/l (Br. Columbia, one industry category)
Nickel	0.2 mg/l (Br. Columbia)
Nitrites (N)	10.0 mg/l (Br. Columbia, for several industry categories)
Nitrogen	2.5 mg/l - April-October 4.0 mg/l at other times
Phenols	0.005 mg/l
Phosphorous	1.0 mg/l
Selenium	0.01 mg/l
Silver	0.05 mg/l
Sulfate	50 mg/l (Br. Columbia)
Sulfides and mercaptans (S)	.011 mg/l (Br. Columbia, one industry category)
Urea	1.0 mg/l (Br. Columbia, one industry category)
Zinc (Ohio at hardness 80 mg/l as $CaCO_3$)	0.075 mg/l (usual 0.1)
BOD_5	30 mg/l (deoxygenating wastes)
COD	125 mg/l
Temperature, maximum	90°F (Br. Columbia, several industry categories)

(continued)

TABLE 168. (continued)

Constituent	Concentration
Turbidity	10 JTU (Br. Columbia, several industry categories)
Solids: Total	1500 mg/l (Br. Columbia, several industry categories)
Dissolved (Total)	1000 mg/l (Delaware R.B.C.*)
Suspended	25 mg/l (Canada-Federal)
Oil	10 mg/l (Delaware R.B.C.)
Persistent pesticides	Not to exceed 1/100 of TL_{50} value at 96 hours appropriate bioassay test (Delaware R.B.C.)
Dissolved oxygen (nontidal streams)	Not to reduce dissolved oxygen content of receiving water by more than 5% (Delaware R.B.C.)
Toxicity	50% max. mortality in 96 hours appropriate bioassay test with 1:1 dilution (Delaware R.B.C.)
pH**	6.5-8.5 (Br. Columbia, several industry categories)

*R.B.C. = River Basin Commission

**The pH limitation should not be subject to averaging and should be met at all times.

E-6.3.4 Other Water Quality Criteria

Criteria include the following:

- Waste treatment ponds - lagoons containing toxic substances or petroleum products must be lined.
- Nondegradation - waters whose existing quality is better than the established standards shall not be lowered in quality.

- Aesthetic values shall not be reduced by dissolved, suspended, floating or submerged matter so as to affect water usage.

E-7 Siting Considerations

Basic siting considerations involved in the use of the joint site selection and impact assessment methodology, discussed in the text (Section 5.0), are detailed in the ensuing paragraphs. Existing state land use requirements that may be important in the development of the synfuels technology are shown in Table 169. Finally, the details of the integration of impact assessment with the site selection process are present in relation to recognized stages in current site selection procedures.

E-7.1 System Planning and Design

System planning and design refer in part, to the development of preliminary coordination with federal, state and local agencies in the region of interest as to the information concerned with: existing water, air, and land quality and use; identification of potential water use, water rights and other conflicts; identification of critical natural areas and air quality control regions, and a host of other activities. These informational contacts will save much time and effort in establishing the necessary working relationships at later stages, and also provide a basis for identifying additional constraints or exclusions to siting in a given region.

Implicit in the system planning category is the development of design features that relate to the environmental, health, and safety issues considered unique to the coal

TABLE 169. STATE LAND USE PROGRAMS (172)

State	Type of program			Coastal zone management[d]	Wetlands management[e]	Power plant siting[f]	Surface mining[g]	Designation of critical areas[h]	Differential assessment laws[i]	Flood-plain management[j]	Statewide Shore lands Act[k]
	Comprehensive permit system[a]	Coordinated Incremental[b]	Mandatory local Planning[c]								
Alabama				X		X	A			X	
Arizona		X				X			A	X	
Colorado						X	X	X	A	X	
Illinois				X		X	A,B		B	X	
Indiana		X		X			A,B		A	X	
Kentucky						X	A,B		B		
Maryland		X		X	X	X	A,B	X	B	X	
Montana		X	X			X	A,B	X	B	X	X
New Mexico		X				X	A		A		
North Dakota						X	A		A		
Ohio				X		X	A		B		
Pennsylvania				X	X	X	A	X	B		
South Dakota							A	X	A		
Tennessee						X	A,B				
Utah		X					A		B		
Virginia			X	X	X		A,B		B		
West Virginia							A,B			X	
Wyoming		X	X			X	A		A		

a State has authority to require permits for certain types of development.

b State-established mechanism to coordinate state land-use-related problems.

c State requires local governments to establish a mechanism for land use planning (e.g., zoning, comprehensive plan, planning commissions

d State is participating in the Federally funded coastal zone management program authorized by the Coastal Zone Management Act of 1972.

e State has authority to plan or review local plans and the ability to control land use in the wetlands.

f State has authority to determine the siting of powerplants and related facilities.

g State has statutory authority to regulate surface mines. (A) State has adopted rules and regulations; (B) State has issued technical guidelines.

h State has established rules, or is in the process of establishing rules, regulations, and guidelines for the identification and designation of areas of critical state concern (e.g., environmentally fragile areas, areas of historical significance).

i State has adopted a tax measure which is designed to give property tax relief to owners of agricultural or open space lands. (A) Preferential Assessment Program: Assessment of eligible land is based upon a selected formula, which is usually use value. (B) Deferred taxation: Assessment of eligible land is based upon a selected formula, which is usually use value and provides for a sanction, usually the payment of back taxes, if the land is converted to a non-eligible use. (C) Restrictive Agreements ment of back taxes if the owner violates the terms of the agreement.

j State has legislation authorizing the regulation of floodplains.

k State has legislation authorizing the regulation of shorelands of significant bodies of water.

liquefaction process; these include: the development of industrial hygiene programs and operating safeguards for suspected carcinogens and related hazardous substances important to human health; the testing and development of equipment and hardware that mitigate the health and other effects of fugitive emissions; the development of effective plans for the disposal of sludges and solid wastes, and the preparation of plans for coping with spills of toxic and hazardous substances (142). By their assorted natures; these efforts will require close interagency coordination and effective cooperation with relevant industrial groups. For example, one company found a way to circumvent the use of engineering controls on workplace noise by the use of personal hearing protection; this resulted in estimated annual savings per worker of $3080 (173).

Detailed discussions of the significance of the EPA offset policy and the PSD regulations of the Clean Air Act, the implications of the 1977 amendments to the Clean Water Act, the Resource Conservation and Recovery Act, and the Toxic Substances Control Act were presented in a previous report (43).

Design considerations can be important with respect to intake structures for the diversion of surface waters for use in cooling towers. As pointed out elsewhere (138) consideration should be given to the location, design, construction and capacity of water intake structures, especially cooling water intake structures, to insure that such structures reflect the best technology available for minimizing adverse environmental impact.

Key environmental factors influencing impingement or entrapment are water temperature and velocity, light intensity, fish concentration and behavioral patterns, low dissolved oxygen concentrations, the presence of toxicants, relative location and construction details of the intake structure, and the location of the intake in relation to the bottom, shoreline, and water surface (43). In situations where the intake water is filtered through the river bed (e.g., the Ranney Collector System) fish life will not be impaired (138).

E-7.2 Regulatory Standards and Criteria

All SRC liquefaction sites must meet the federal, state, and local environmental requirements for air, water, land (solid wastes), products and by-products, nonchemical pollutants (noise and thermal factors) and hazardous wastes and toxic substances during the constructional, operational, and post-operational phases. These factors represent a significant portion of the several areas of conflict that have arisen between federal and industrial groups since the adoption of the 1977 amendments to the Clean Air and Clean Water Acts. Subcategories of the so-called regulatory imperative include the following:

- The effect of the emissions and effluents resulting from construction and operation of the plant on the environment.
- The effect of the environment (e.g., floods, tornadoes, earthquakes, etc.) on the facility.

Because of this dichotomy, it is understandable how these two subcategories interact significantly with design, engineering, economic, and institutional factors (144).

E-7.3 Engineering Factors

Engineering factors come into play both in terms of the site related and the technical design factors. Site related factors must be well researched in order to make effective use of technical design factors and vice versa, both during the construction and operation of the synfuels facility. For example, slope and topography dictate the degree of environmental protection required during clearing and grading operations; these factors are also important in terms of the amount of borrow soils needed for fills, the size of borrow pits and soil stockpiles, engineering geology, soil stability under foundations, and the suitability of the subsurface soils for impoundments, cooling ponds, and wastewater disposal ponds. The number and complexity of site related factors to be considered depends upon the stage of siting and the need for site specific impact assessments. For example, deficiencies in site related factors relative to environment/impingement can be overcome by use of sometimes costly engineering designs.

In general, the most important engineering design factors relate to an abundant supply of coal and water, with an ample transportation infrastructure (including pipelines) to move coal feedstock, the products and by-products, and the solid wastes to their destined places. Other design factors include: seismology and structural details; soil permeability beneath solid waste disposal sites; land access and acquisition; availability of construction materials and labor; general layout of plant and auxiliary units, and the preparation of erosion and sediment control and related plans during the construction phase.

E-7.4 Natural Environment - Abiotic and Biotic Considerations

The physical, chemical and biological features of specific areas must be well understood if detailed impact assessments are to be made, as in Stage 3 of the siting process. During Stage 1, interest centers largely on the identification of natural land reserves and federal lands, the location of adequate coal reserves and water, and the potential for intrusion into sensitive ecosystems or endangered species. In Stage 2, seismic, climatic, hydrologic, topographic, and surficial geology factors are among the most crucial.

E-7.4.1 Abiotic (Physical) Considerations

Abiotic features essentially determine the structure and diversity of aquatic and terrestrial ecosystems, as well as the dispersion of contaminants in air, water and on the land. Among these latter items are: surface water supply and its quality; groundwater supply and quality; stream low-flows; air dispersion and stream flushing patterns; existing air quality; land drainage patterns and related hydrologic features, and natural landmarks, trails and scenic rivers. The generic interaction of these factors with each other, and with biotic features was discussed in an earlier report (43) for a specific site.

E-7.4.2 Contamination of Groundwater with Regard To Coal Liquefaction

Two major potential sources of groundwater pollution associated with the SRC system are surface impoundments of various liquids and solid waste landfills. Impoundments in the form of tailings ponds or sludge dewatering lagoons are surface depressions in which waste fluids are pumped or drained to the pond via pipeline or drainage ditch. The suspended solids then settle to the floor of the pond and the remaining portion (effluent) is either reused, discharged into local surface water, or spread on land. As the solids settle, the pond fills with sediment and is either abandoned or dredged to create new storage space.

Seepage is the most prevalent source of groundwater contamination from ponded wastes. Other routes by which impoundments may contribute to pollution problems are through pond overflow and dike leakage, both of which can recharge a local aquifer with contaminated water. Also, prior to abandonment of the waste site, failure to properly cover the area (thus preventing or limiting the rainfall infiltration) could result in the area continuing to be a contamination source.

Solid waste land disposal sites associated with SRC systems can also be sources of groundwater contamination, because of the generation of leachate caused by water percolating through the refuse. Precipitation falling on a site either becomes runoff, returns to the atmosphere via evaporation and transpiration (water use by plants), or infiltrates the refuse. This infiltrating water ultimately will form leachate containing soluble and suspended contaminants.

The process of leachate formation and subsequent groundwater contamination is dependent upon the amount of water which passes through the refuse. Water which infiltrates the surface of the cover will first be subject to evaporation and plant transpiration. Any water in excess of field capacity will percolate through the layers of solid waste. Additional surface runoff from the surrounding land, moisture contained in the solid or liquid waste placed in the fill, moisture from solid-waste decomposition, and water entering through the bottom or sides of the site also contribute to the generation of leachate.

Figure 118 illustrates the flow of contaminants from a surface source such as a disposal pit, lagoon, or basin. Note that the contaminated water flows downward to form a recharge mound at the water table and then moves laterally outward below the water table.

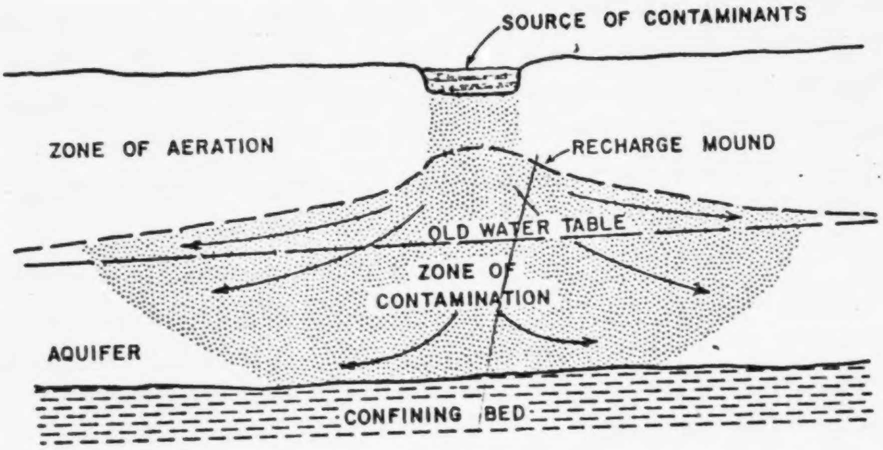

SOURCE OF CONTAMINANTS
ZONE OF AERATION
RECHARGE MOUND
OLD WATER TABLE
ZONE OF CONTAMINATION
AQUIFER
CONFINING BED

Figure 118. Diagram showing percolation of contaminants from a disposal pit to a water-table aquifer (43)

Figure 119 indicates contaminant movement from a surface stream or lake to a nearby pumping well. The drawdown of the water table induces recharge of surface water to groundwater. Thus, continuous pumping from municipal water supply wells located adjacent to a polluted stream may lead to the contamination of the water supply.

E-7.4.3 Mechanism of Contamination

Contaminants in groundwater tend to be removed or lowered in concentration with time and with distance traveled. Mechanisms involved include adsorption, dispersion, dilution, and decay. The rate of attenuation is a function of the type of contaminant and of the local hydrogeologic framework. Attenuation in an aquifer is extremely slow as is the movement of groundwater (typically less than 0.6 m/day). Therefore, contaminants within the groundwater system do not mix readily with native water and move as: (1) individual bodies or slugs (e.g., caused by intermittent filling of and seepage from wastewater impoundments); (2) local plumes (e.g., caused by continual flow of leachate from beneath a landfill toward a pumping well); and (3) masses of degraded water (e.g., caused by a large number of septic tanks discharging nitrate-enriched water which travels with the regional groundwater flow pattern).

Specific statements cannot be made about the distances that contaminants will travel because of the wide variability of aquifer conditions and types of contaminants. Also, each constituent from a source of contamination may have a different attenuation rate, and the distance over

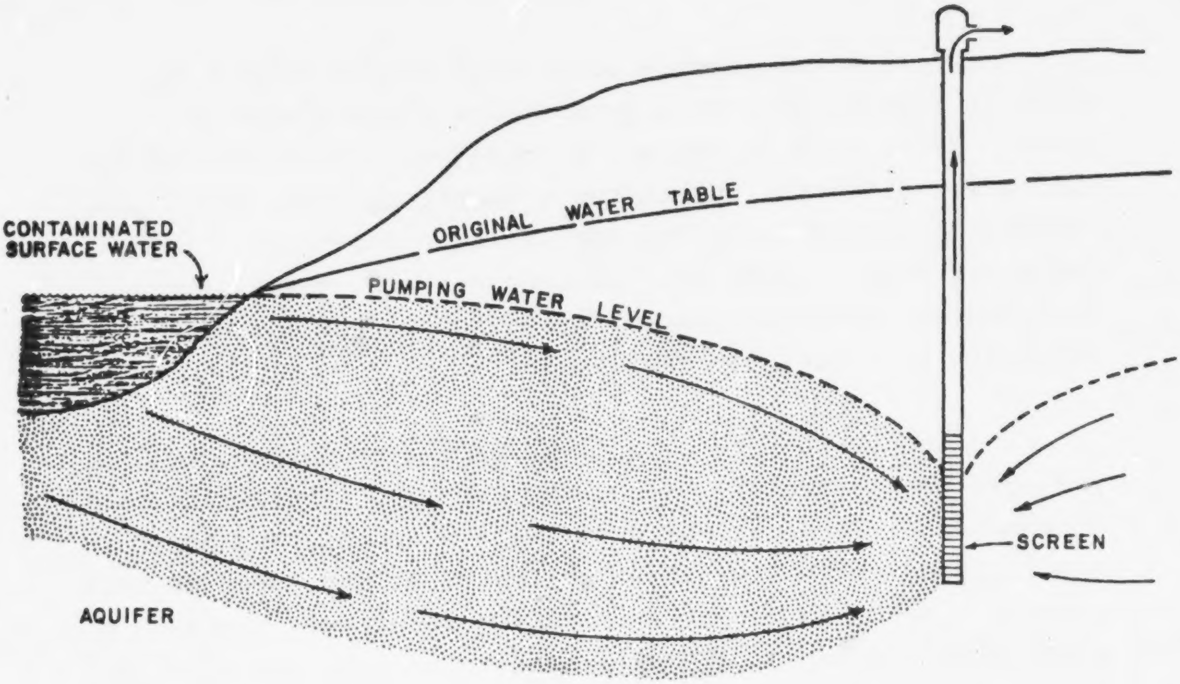

CONTAMINATED SURFACE WATER
ORIGINAL WATER TABLE
PUMPING WATER LEVEL
SCREEN
AQUIFER

Figure 119. Diagram showing how contaminated water can be induced to flow from a surface stream to a well (43)

which contamination is present will vary with each component. Yet, certain generalizations can be made. For fine-grained alluvial aquifers, contaminants such as bacteria, viruses, organic materials, pesticides, and most radioactive materials, are usually removed by adsorption within distances of less than 100 m. However, most common ions in solution move unimpeded through these aquifers, subject only to the slow processes of attenuation.

A hypothetical example of a waste disposal site is shown in Figure 120. Here groundwater flows toward a river. Zones A, B, C, D, and E represent essentially stable limits for different contaminants resulting from the steady release of liquid wastes of unchanging composition. Contaminants form a plume of contaminated water extending downgradient from the contamination source until they attenuate to acceptable quality levels.

The shape and size of a plume depend upon the local geology, the groundwater flow, the type and concentration of contaminants, the continuity of waste disposal, and any modifications of the groundwater system by man, such as well pumping. Where groundwater is moving relatively rapidly, a plume from a point source will tend to be long and thin; but where the flow rate is low, the contaminant will tend to spread more laterally to form a somewhat wider plume. Irregular plumes can be created by local influences such as pumping wells and variations in permeability.

In marked contrast to surface-water pollution, groundwater contamination may persist for years, decades, or even centuries. The average residence time of groundwater is on the order of 200 years; consequently, a contaminant which is not readily decayed or sorbed underground can remain as a

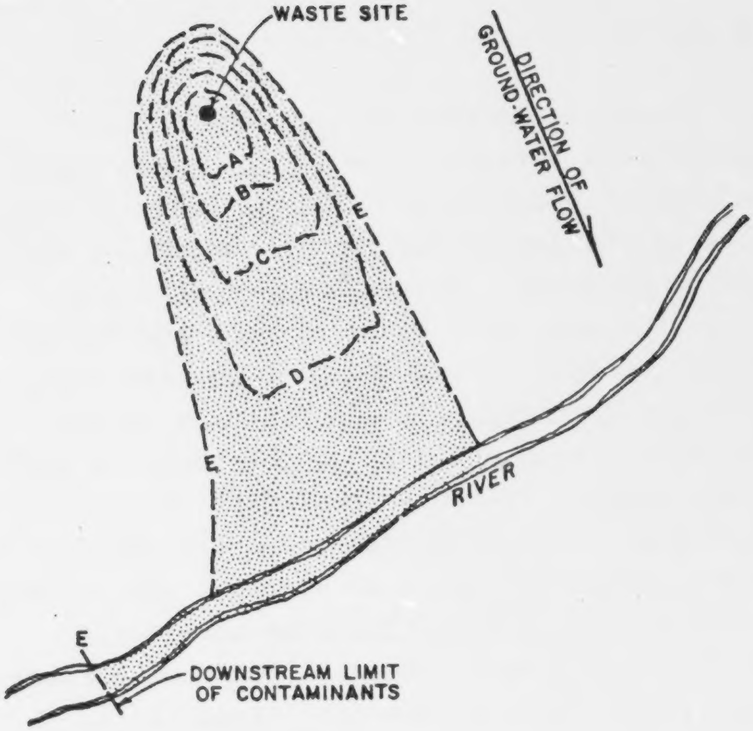

WASTE SITE
DIRECTION OF GROUND-WATER FLOW
A
B
C
D
E
E
E
RIVER
DOWNSTREAM LIMIT OF CONTAMINANTS

Figure 120. Plan view of a water-table aquifer showing the hypothetical areal extent to which specific containmants (represented by the Letters A, B, C, D and E) of mixed wastes at a disposal site disperse and move) (43)

degrading influence on the resource for indefinitie periods. Comparable residence time for water in a stream or river is on the order of 10 days. Controlling groundwater contamination, therefore, is more difficult than controlling surface water contamination. Underground contamination control is best achieved by regulating the source of contamination. A seconary control is physical entrapment and, when feasible, removing the contaminated water from the underground.

E-7.4.4 Geology (Abiotic)

The U.S. Soil Conservation Service and most state geological surveys provide various criteria for large-scale site screening and impact assessments. One of these is the slope from which estimates can be made of the amount of soil and rock materials to be moved. Some states require that routine estimates of the area and volume of cuts and fills shall be included in the erosion and sediment control plan as a contingency to the granting of a construction permit. Included with the latter is an estimate of the location and extent of borrow pit areas. As a matter of fact, the regulatory process incurs many costs, referred to as transaction costs (115). These include the costs of hearings and public meetings, costs of time losses resulting from unresolved issues of various kinds, and costs incurred for environmental monitoring and baseline surveys at specific sites (115).

E-7.4.5 Soil Factors

Soil organic matter is capable of reacting with, or chelating a number of elements, possibly by the carboxyl or phenolic hydroxyls, especially in chelation. There appears to be at least three different sites for the absorption of zinc. Copper, tin (II), and lead are especially strongly bonded by humus, so much so that many peaty soils contain too little soluble copper to support the growth of crops. Zinc is less strongly bonded and can be leached from certain organic soils by solutions of pH less than 5. Manganese (II), calcium, magnesium, and the alkali metals are readily leached out (174).

The amount of phosphate organically bound in soils can vary from 25 to 85 percent. Germanium, molybdenum, selenium, uranium and vanadium may be retained by alkaline peat while borate, sulphate and nitrate are not retained. Bromine and iodine may be strongly absorbed by humus from the atmosphere and from solution (174).

The small organic molecules present in soils include the common amino acids, acetic, butyric, citric, formic, 2-ketogluconic, malic, oxalic, tartaric and a variety of lichen acids. The main effects of these acids are to lower the pH of the soil solution, to increase the rate of dissolution of primary minerals, and to chelate and so render more soluble many elements such as aluminum, copper, iron, nickel, phosphorous and zinc (174).

Oxidation and reduction of arsenic, iodine, molybdenum, selenium, tellurium, uranium and vanadium are known to occur in soils. In well-drained soils which are rich in nitrates, As (III) is transformed to As(IV), Se(IV) is changed to Se(VI), Te(IV) gives Te(VI) and even I(I) can be changed to I(V). On the other hand in more or less reducing conditions As(III), Se(IV), and Te(IV) may be changed to the elemental form or to volatile di- or trimethyl forms. The soil fungus, Scopulariopsis brevicaulis, can reduce arsenite to trimethyl-arsenic and the soil bacteria, Micrococcus lactilyticus, reduces the higher oxidation states of many elements including As, Fe, Mn, Mo, N, S, Se, and Te (174).

The most important surface soil properties affecting the potential distribution, and/or ecotoxicological effects of inorganic and organic contaminants, relate to the effectiveness of the organic and inorganic (clay) colloids in sorbing or trapping potentially toxic substances, soil pH, percolation rate, level of organic matter, and the activity of microorganisms.

The greater adsorptive capacities of the fine particles of clay and silt (i.e., particle diameters of one micron or less) compared to sand particles is widely recognized. Soil colloids are described as complex aluminosilicates coated with organic substances, broadly referred to as humic complexes; these organoaluminosilicate complexes exhibit selective ion adsorption. Many mineral colloid surfaces are covered with a coating of hydrous oxides of iron and manganese. These exist in amorphous or microcrystalline forms and in themselves exhibit a high specific surface area; up to 300 square meters per gram. The oxygen and hydroxyl groups of the hydrous oxides exert electrical charges which are pH dependent. Therefore, their capacity for sorption is pH dependent.

The dissolution and deposition of the coatings are also dependent upon the oxidation-reduction (redox) potential in the system. This parameter then becomes indirectly important in the adsorption or desorption of heavy metals. Sorption and desorption of metals further depends upon their concentrations in the percolate and upon the ones present. As with clays, there is an order of selectivity in adsorption. It is quite possible, however, that some heavy metals may move into the groundwater system prior to the exhaustion of exchange capacity.

In general, the amount of negative charge and surface area of clays is dependent on the clay type, being lowest for the kaolinite type and highest for the montmorillonite type. The negatively charged points of the clay surface hold cations (which carry a positive charge) by electrostatic and van der Waals forces. Usually the attraction is proportional to the positive charge on the cation. The upper limit for fixation of cations is referred to as the cation exchange capacity (CEC), and that of anions is known as the anion exchange capacity (AEC) (175). When the cation saturation point is reached, the percolate composition will remain stable. Factors affecting CEC and AEC include soil solute concentration, pH, and percolation rate. Thus, no quantitative predictions of the sorption characteristics can be made short of a site-specific analysis.

Recent work by Johnson and Cole (181) indicates that anion production (HCO_3^-) and leaching (N and P) can be used effectively as an index of total ionic leaching through soils. In general, the order of affinities of major anions is $PO_4$3-, $SO_4$2-, Cl^- = NO_3-. Highly weathered iron and aluminum-rich soils have higher adsorption capacities than the younger iron and aluminum-poor soils.

E-7.4.6 Microclimatic Changes Resulting from the Construction and Operation of SRC Plants

As much as 160 x 10^{12} joules of heat could be lost to the environment during each day that a commercial-sized SRC plant is in regular operation (43). In an effort to establish once for all whether the release of heat from power plants and moisture from natural draft cooling towers and cooling ponds can affect local climates, the U.S. Department of Energy launched the so-called METER program in 1976 at four coal-fired power plants in the U.S. These results, though useful, cannot be expected to produce an accurate assessment of localized climatic effects of the heat release from an operating SRC plant. In the second place, the precise location of the operating SRC plant will be critical. For example, if located near large metropolitan areas, such plants would not likely exert any measurable impacts on local climates since they would form but a fraction of the total heat island. If located in remote areas the impacts of heat release would be controlled largely by the air dispersion characteristics of a specific site. According to the AFDP report (138), the introduction of inadvertent changes in local or regional weather patterns through the construction and operation of synthetic fuel plants, intensive surface mining, and other conjunctive developments warrants careful consideration. Even slight changes in rainfall could be significant in areas where agriculture relies on marginally adequate rainfall or snowmelt.

The most frequently cited factor associated with inadvertent climate modification is the increasing carbon dioxide (CO_2) content of the atmosphere (182). The observed steady growth in carbon dioxide concentration is attributed to the rapidly increasing use of fossil fuels since the turn of the century. Although the potential effects of atmospheric carbon dioxide on global temperature and climate have serious implications (the greenhouse effect through which the temperature could increase), no significant localized or regional weather effects from carbon dioxide emissions are anticipated from synthetic fuels development, due to the relatively small quantity of carbon dioxide expected to be produced from synthetic fuels production in relation to production from other sources. However, the CO_2 emission from several point sources within the standard SRC plant and auxiliaries is estimated to be about 13,000 Mg/day (43).

The precise role of airborne particulates and other aerosols emanating from synthetic fuels facilities with regard to weather modifications cannot be determined completely. Their influence on the amount of short-wave solar radiation is well established and has important implications both on a global (182) and regional scale. In principle, aerosol particles could also act as condensation nuclei and either enhance or inhibit rainfall. A considerable body of knowledge regarding cloud seeding has been built up over the past 25 to 30 years (182) and numerous precipitation management programs are in progress, notably in the U.S., Australia, Israel and the Soviet Union. While certain aspects of intentional weather modification are still regarded as controversial, it is generally recognized that artifical nucleation can be effective in producing increases or redistributions of precipitation under very specific meteorological conditions and through the use of appropriate techniques. A definitive answer as to whether or not a local increase in the concentration of atmospheric aerosols resulting from dust or industrial emissions would cause a significant change in precipitation patterns cannot be given (176). A few instances of anomalous snowfalls have been recorded; industrial and urban emissions are thought to be instrumental in producing generally light snowfalls in these cases (176). An increase in cloudiness due partly to the aerosol condensation nuclei and partly to the heating effect of cleared surface areas appears to be a more likely regional phenomenon than persistent alterations in precipitation characteristics. This could affect the enjoyment of scenic views by the recreational sightseers. Differences in climatic conditions and the nature of the airborne particulates could make this a more severe problem in the Four Corners, Powder River and Fort Union Regions than in the Eastern Interior or Appalachian Regions (43).

Many studies (176) have indicated that precipitation is increased downwind of power generating facilities and other industrial complexes. Usually, this increase takes the form of increased severe storms; this may be due to a thermal effect caused by heat losses to the atmosphere or to an increased particulate count. Such an effect is possible in remote areas downwind of a commercial-sized SRC facility. If an increased precipitation occurs on a local basis, two detrimental effects are possible. First, since most rainfall of greater than 1.25 to 2.5 cm does not increase crop yield but rather leads to erosion (176), the area receiving an increased rainfall could be damaged due to increased erosion, hail, lightning damage, etc. Second, the weather modification induced by the industrial facility may lead to a depletion in the moisture content of the air due to the increased precipitation immediately downwind of the facility. This latter effect could lead in some regions to partial drought conditions further downwind of the plant.

Drift of the vapor plume from the cooling tower could promote fogging and icing conditions. If this drift occurs near highways, hazardous driving conditions could result. As a rule, this action is limited to a 610 to 910 meter radius from the tower (43).

E-7.4.7 Biotic Considerations

Biotic features become increasingly important starting about midway through Stage 2 and into Stage 3 where detailed information on aquatic and terrestrial ecosystems is collected via baseline inventories at specific sites. Biotic considerations of greatest concern usually relate to threatened and endangered species, sensitive ecosystems, value of habitats for fish and wildlife, and the plant and animal species making up the agroecosystems.

The activities of soil microorganisms must be recognized in predicting the movement and composition of leachates. For example, under anaerobic soil conditions, microbes may convert trace elements to the less mobile sulfides. On the other hand, these activities under aerobic soil conditions may facilitate leaching of trace elements with subsequent passage into lower layers. The downward movement of trace elements in the soil column is a function of cation exchange, Eh, pH, and organic colloids. Trace elements with vacant d-orbitals, such as Cu, Zn, Fe, Mn, and Mo tend to be bound to soil organic matter. On the other hand, acidic soils tend to have high trace element availabilities (e.g., Mn and Ni) to the roots of crop plants. For selenium, the availability to plant roots in neutral to alkaline soils is reported to be greater than that in acidic soils, directly opposite to Mn and Ni.

Table 170 shows some of the abiotic and biotic factors influencing the environmental transport of trace elements in soils. Key factors are the availability of trace elements for uptake and potential bioaccumulation by plants, ability of trace metals to travel through soil to groundwater, and the immobilization of trace metals in surface layers of soil

TABLE 170. INTERACTIONS OF SELECTED ELEMENTS IN SOILS (43)

Element	Microbes capable of changing chemical form	Bound by soil organic matter	Solubilized by acid production or chelation	Poor soil drainage increases availability
Aluminum			+	
Antimony	+			
Arsenic	+		+	
Barium				+
Beryllium		+		
Boron		- (b)		+
Bromine		+		
Cadmium		+	+	
Calcium		+ (a)		
Chromium	+			+
Cobalt	+		+	+
Copper	+	+	+	
Gallium				+ (e)
Germanium		+		
Iodine	+	+		
Iron	+	+	+	
Lead	+	+	+	
Magnesium		+ (a)		
Manganese	+	+ (a)	+	+

(continued)

TABLE 170. (continued)

Element	Microbes capable of changing chemical form	Bound by soil organic matter	Solubilized by acid production or chelation	Poor soil drainage increases availability
Mercury	+		+	
Molybdenum	+	+		+
Nickel	+		+	+
Nitrogen	+	– (c)		
Phosphorous		+	+	
Plutonium	+			
Selenium	+	+		–
Silicon	+			
Sulfur	+	– (d)		
Tellurium	+			
Thallium			+	
Tin	+	+		+ (e)
Titanium	+			
Uranium	+	+		
Vanadium	+			+
Zinc	+	+ (a)	+	
Zirconium		+		

(a) Relatively easy to leach from soil organic matter.
(b) As borate.
(c) As nitrate.
(d) As sulfate.
(e) Not in all cases.

from which it can be transported to nearby ecosystems by surface runoff, erosion, or wind blown dust. Most nonpoint pollution sources can be attributed to the transport of contaminated sediments. Most cationic trace metals are immobilized in soil and are present in concentrations which could not pose a threat of groundwater contamination unless they are metylated (e.g., Hg), but anionic groups may pose a potential hazard. A thoretical study of the potential impact of coal gasification plant on the trace element levels in soils surrounding the plant after 40 years of operation identified copper, mercury, molybdenum, and tin as elements whose endangerous soil levels would be greatly exceeded (177).

E-7.5 Socioeconomic and Sociocultural Considerations

As pointed out elsewhere (138), a series of effects on the human environment can be expected to result directly from the construction and operation of a synethtic fuels facility; these include economic, demographic, geographic, social, cultural, land use, and water use effects on target community (138). Table 171 (column two) shows the total impact scores derived for six different candidate sites by use of a formalized numerical rating and weighting system (144). Thirteen different types of specific impacts constituted this analysis, as shown in the footnote section of Table 171. The application of formalized numerical rating techniques requires the use of the following (144):

- Development of a hierarchical structure or matrix for assessing impacts on the human and natural environments

TABLE 171. ENVIRONMENTAL IMPACT ANALYSIS - MOST SIGNIFICANT SPECIFIC IMPACTS OF POWER PLANT CONSTRUCTION (144)

Sites-In Order of Increasing Total Impact	Total Impact Scores	HIGHEST		INTERMEDIATE		LOW		LOWEST	
		Type of Impact	Percentage of Site Total	Type of Impact	Percentage of Site Total	Type of Impact	Percentage of Site Total	Type of Impact	Percentage of Site Total
1 - Cooling tower	264	A*	16.	G*	14.	H*	11.	I*	9.
3 - Cooling pond	522	B*	19.	H*	14.	C*	12.	G*	7.
5 - Cooling tower	526	C*	16.	A*	14.	K*	12.	B*	9.
2 - Cooling pond	596	D*	20.	F*	19.	L*	11.	E*	6.
6 - Cooling pond	715	E*	13.	I*	10.	A*	10.	B*	7.
4 - Cooling tower	1000	F*	12.	J*	12.	E*	12.	M*	9.

*Specific Impact Types (Partial Listing)

A - Transmission Line Construction
B - Loss of Recreational Land
C - Surface Water
D - Uniqueness of Habitats
E - Loss of Natural Habitats
F - Displaced Homes
G - Icing of Flora
H - Visual Exposure
I - Construction Activity
J - Damming and Ponding
K - Dissolved Solids Release
L - Irreversible Loss of Land Area
M - Increased Turbidity Surface Water

- Assignment of values to the perceived impacts

- Application of specific impact models for combining specific impacts into a composite value for total impact, usually by use of a computer (144).

Two examples will illustrate the use of a specific impact models, with reference to impact types "D" (uniqueness of habitat) and "F" (displacement of homes) shown in Table 171, as follows (144):

- "Uniqueness of habitat" is described as the percentage of such habitat occuring at the site as compared to similar unique habitats within a 15-mile radius of the site.

- "Displacement of homes" is described by the number of dwellings impacted by the site acquisition.

In Table 171 impact types A through H made the greatest contribution to total impacts at the six candidate sites.

An important contribution to the methodology for assessing adverse and beneficial impacts resulting from the construction and operation of synthetic fuels (i.e., coal conversion) technologies, relates to the Site Evaluation for Energy Conversion Systems methodology (SELECS) developed for the U.S. Department of Energy (DOE) by the Center for the Environment and Man (CEM) (178). After reviewing more than 30 impact methodologies, and three major environmental impact statements related to energy resource development, CEM established eight criteria that an impact methodology should meet, developed an underlying rationale, and prepared a User's Guide for organizing and presenting the numerical results in the so-called Level 1 SELECS methodology (184). In the forthcoming report, CEM will outline two additional, more complex levels suggested for future development. Level 2 would be computer-automated and would provide numerical ratings for the four categories of a project: construction, operation, shutdown, and post-shutdown. The Level 3 SELECS methodology would address air and water quality, water supply, and community services at potential sites (178).

Impacts resulting from the interplay between the primary industry development impacts and the multitude of community variables are referred to as end impacts and include the following items:

- Changes in traditional local life styles
- Changes in local economic functions
- Job opportunities and wage scales for qualified local residents relative to those for the local, long established core activities
- Changes in local government finances
- Changes in local crime rate
- Changes in local markets and prices for essential goods and services
- Indian land ownership relative to coal
- Local water rights and water allocation conflicts.

During Stage 2 of the process, it is essential that a broad array of socioeconomic and sociocultural factors be included in the considerations to be screened. For example, public attitudes about the compatibility of a synfuels plant with the local infrastructure, and the public perception of the environmental and economic benefits of a synfuels plant ought to be identified as early as possible in Stage 2 at the local level. The necessary intergovernmental and industrial cooperation/coordination required to assist local groups to cope with some of the key issues, both in the short- and long-terms would be essential in Stage 2. As the number of potential sites is narrowed, sufficient lead time would be available to launch the programs necessary to resolve conflicts so that Stage 3 would result in more clear cut selection of the most suitable sites (138,144).

Existing state land use programs that may be useful in coordinating the planning of synfuels development are shown in Table 169, there are no extant federal statutes for this purpose (138,144). At the local level, zoning ordinances and master plans are often available to coordinate various land uses.

Another aspect of the land use issue refers to the prime farmland concept of the U.S. Department of Agriculture. Prime farmland is defined as soil associations considered best suited to the production of food, forage, fiber and oilseed crops, based on soil characteristics that include soil fertility, soil moisture and other physical criteria. The proper combination of these criteria, when applied to specific soils so as to produce sustained high yields of crops, can result in such soils being designated as prime farmland (43). Agricultural lands and water uses could be lost to other uses such as community expansion synfuels plants and other uses.

Finally, a U.S. Department of Housing and Urban Development (HUD) program to achieve management of the nation's flood plains requires state and/or local assurances that efficient land use policies, as established by HUD criteria, be adopted and enforced to regulate land use and future development in these areas. The program would provide insurance at subsidized rates on certain existing structures and their contents, but would serve as a deterrent to continued, unregulated construction in designated flood prone areas (43).

E-7.6 Institutional Factors

Institutional factors exert both direct and indirect effects on the overall siting process. More than 17 states now require the submittal and approval of plans for mitigating soil erosion and overland flows of surface runoff as a prerequisite to granting construction permits. This situation characterizes many environmental approvals and site certifications presently required at various levels of government.

As described in a previous report (43) both the owner and the constructor of a coal conversion facility must be in compliance with more than 14 federal approvals, and obtain more than 15 state and local certifications and permits before commencing construction operations (43). In addition to this are the extant federal land management plans of the bureaus of Land Management and Indian Affairs (USDI) and the U.S. Forest Service (USDA). Local restrictions exert direct effects on the siting of synfuels plants today. In areas where earthquake hazards exist (e.g., the state of Indiana) uniform building codes are applicable to new building construction. With reference to the disposal of various hazardous wastes in the state of Illinois, the disposal site shall be buffered by at least 3.04 meters of soil having a coefficient of permeability not greater than 1 x 10^{-8} cm/sec, or not less than 3.04 meters of soil which can provide a containment life lasting 500 years; for less hazardous substances a containment life of 250 years is required (IEPA). Other regional aspects of institutional factors are described in a previous report (43).

Indirect effects of institutional factors include the 1977 amendments (vis-a-vis, PSD and nonattainment areas) to the Clean Air Act which will likely cause licensing delays, increase the cost of building and operating commercial synfuels plants, and limit the number of acceptable sites for synfuels plants. Substantive land use and industrial growth limitations are found in the Clean Air, Clean Water, and Toxic Substances Acts; these factors act indirectly to limit the site selection process as well as the potential impacts of synfuels plants.

Other significant indirect effects refer to the energetic pursuit of federal and state policies encompassing the following areas:

- Development of criteria for locating synfuels plants in remote areas (i.e., generally seven miles to outer boundary of the low population zone)

- Adoption of siting statutes by state governments that provide streamlined application permit procedures

- Incorporation of the costs of environmental damage resulting from the construction and operations of synfuels facilities into the price of energy via regulatory procedures

- Pursuit and execution of basic and applied research programs that, under realistic conditions, permit the selection of the proper plant operating conditions and equipment design concurrently with the assessment of the health and ecologic risks. As new technologies are developed to a demonstration (or higher) status, private enterprise should be encouraged to finance the commercialization of the preferred new design and operating parameters (145)

- Clarification of water rights and the equitable allocation of water to current and future uses particularly with reference to the Colorado River and other compacts

- Suitable recognition of the special attributes of Indian ownership of coal lands in the Four Corners region of New Mexico and Arizona and in the Fort Union - Powder River Regions (Wyoming, North Dakota, and South Dakota).

E-7.7 Impact Assessment and Determination of Proposed Sites

The assessment of impacts generally begins on a rather qualitative basis in Stage 2 of the site selection process. In Stage 3, however, greater emphasis is placed on the quantification or ranking of impacts and the combination of an appropriate mix of considerations (i.e., with primary emphasis on design engineering, economic costs, and environmental factors) to derive impact values and to determine several acceptable sites (144).

Specific impact models are recommended to deal singly with each impact independently of all other impacts. For example, the U.S. DOE used a community development programming model to generically estimate both the development impacts and the end impacts of synthetic fuels plant construction and development in the United States (AFDP).

Ramsay (115) inspired by the approaches to power plant siting being used by the State of Maryland and other groups, suggested a method of site selection whose goal was the identification of the relative suitability of different types of power plants at different geographic locations for each reasonable permutation of a set of specific plant design technologies, whereupon the environmental impacts and dollar costs were determined sequentially in terms of the following environmental categories: geology, seismology; meteorology, population centers; hydrology; ecosystems, land use, and several other factors (115). The rationale of this approach was that an attempt be made to measure all economic, plant design, and environmental variables in terms of dollar values. In fact, this effort is made somewhat easier by the existence of federal and state regulatory standards which must be met on a site specific basis; these factors establish the bottom line for the external costs of compliance (115). The attractiveness of the Ramsay concept (115) stems from its relevance to the dual need to select suitable site(s) on the one hand, and on the other to conduct full-scale assessments of expected environmental impacts. However, this approach will require solid information on a number of variables, not the least of which is the need for compliance with the extant environmental standards, and the cost-effectiveness of the required controls (see also Section 5) at specific sites.

Certain rather formalized numerical rating and weighting systems in current use (144) require (a) procedures for structuring the individual components of total impact, (b) methods for modeling, evaluating, and assigning numerical ratings to those nontangible siting factors listed earlier in Section 5.8, and (c) appropriate models for combining the specific impacts into a composite rating of total impact (144,180). Thus, the structured nature of this method serves to formalize the subjective aspects of the process. Delphi and related techniques probably will be increasingly used to resolve this problem. The following steps have been suggested for use in evaluating site-specific impacts (144):

1. Establish the objectives of the analysis, involving a determination of how impacts are to be measured and classified on a relative comparison basis.

2. Classify impact considerations, involving the structuring of an environmental matrix or hierarchical system.

3. Develop models for each specific impact. A key element of the formalized numerical rating methods is the way in which each of the individual specific impacts is described or modeled. Ideally, each impact should be treated independently of all other impacts and evaluated by the same ground rules at each site. To the greatest extent possible, specific impacts should be based on objectively measured quantitative data; however, judgmental

assessments will inevitably be present to some extent.

Examples of specific impact models are as follows, (144):

- Displacement of residences

  The environmental impact of displacing people is assumed to be proportional to the number of dwellings affected by site acquisition.

- Uniqueness of habitats

  The environmental impact of loss of a particular portion of natural habitat is modeled as the percentage which occurs on the site with respect to similar types of habitat within, say, a 24 km radius on the site.

4. Develop a list of data requirements. The requirements for input data will depend upon the particular specific impact models developed. The limiting constraint is the quality and quantity of data that can be obtained for a reasonable amount of effort.

   Examples of sources that can be used include:

   - Current 7-1/2 minute or 15 minute series U.S.G.S. topographic maps

   - Current U.S. Census reports

- County Plat books
- U.S. Department of Interior Water Supply Papers
- Reports for the local State Departments of Natural Resources
- Local hunting and fishing guides

5. Establish weightings and determine site rankings. Since all specific impacts are not of equal importance, the significance of each relative to the others is usually factored into the evaluation using an importance weighting for each specific impact. Following the application of a particular weighting scheme, the order of site ranking is determined by using the evaluation structure from Step 2, and the models from Step 3. Employing different sets of importance weightings can be used to investigate the sensitivity of total impact to particular considerations.